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APPS-IV
Remote sensing
applications guide

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This report describes the Computer-Assisted Photo Interpretation Research (CAPIR) facility at the U.S. Army Engineer Topographic Laboratories (USAETL) and discusses its use, primarily with the APPS-IV analytical stereoplotter, for various remote sensings applications. The components of the APPS-IV and the geographic information system (AUTOGIS) are described, followed by discussions of the capabilities and advantages of a CAPIR-type system. A general workflow is also included as a guide to the undertaking of this type project.

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Preface

This report was generated under Contract DAAK70-81-C-0261 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060, by Autometric, Incorporated, Falls Church, Virginia 22041. The Contracting Officer's Technical Representative was Mr. Laslo Greczy. The Contract Project Manager was Mr. Alan F. Smith. Major contributions to this report were made by Mr. Smith and Mr. Jonathan Howland (formerly with Autometric, Inc.)

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1.0   INTRODUCTION

Technology today has presented man with a means of monitoring the environment through the use of photographs, radar, and other remotely sensed imagery (e.g., multispectral scanner imagery, thermal IR images). Many different disciplines, from forestry and geology to engineering and regional planning, are able to make use of these various types of data, but they require a means of extracting only that data which are pertinent to their specific needs. Since these investigations utilize maps, aerial photography and other types of remote sensor data, accurate measurements and data integration techniques are vital to the success of a project. Such efforts can be carried out very efficiently using the APPS-IV (Analytical Photogrammetric Processing System-IV) along with AUTOGIS (Automated Geographic Information System).

The purpose of this APPS-IV Remote Sensing Application Guide is to introduce the APPS-IV/AUTOGIS system and its capabilities as related to remote sensing data. This Guide provides a procedural outline for typical APPS-IV/ AUTOGIS project work, and points out advantages of using this system as opposed to other forms of data collection and manipulation. It is not intended to present a comprehensive guide to remote sensing interpretation and procedures. These subjects are covered in many texts, notably the Manual of Remote Sensing (1975), Manual of Photogrammetry (1980), and the U.S. Army Corps of Engineers Remote Sensing Guide (1979).

1.1   Background

During the past few years many Federal agencies have turned to the computer for storing, retrieving, analyzing, manipulating and displaying map information. This trend is especially true of agencies such as the Corps of Engineers (COE) that use remotely sensed imagery to collect and display information for planning and general land management decision-making purposes. Many new techniques and technologies have resulted. Approximately three years ago, recognizing the value of these technological developments, the COE developed the Computer-Assisted Photointerpretation Research (CAPIR) facility at the U.S. Army Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia.

The CAPIR system uses an APPS-IV analytical stereoplotter interfaced to a host computer and AUTOGIS. The APPS-IV enables the photo analyst to view images in

stereo, thus enabling the operator to accurately identify, locate and measure features and their dimensions on the earth's surface. Interpretation, mensuration and digitization can be carried out simultaneously, thereby reducing the number of individual steps and time required to complete a project.

The AUTOGIS software, originally developed for the U.S. Fish and Wildlife Service by Autometric, Inc. and the Federation of Rocky Mountain States, controls all setup, digitization (both from an X-Y digitizing table and the APPS-IV), and data manipulation for the CAPIR system. By enabling the user to automatically integrate and synthesize multiple data sets by means of scale change and digital overlays, correlations can be developed among data sets that would not be readily achieveable by manual methods. Other functions, such as database management and display, are easily handled by AUTOGIS. Together the APPS-IV and AUTOGIS form the nucleus of CAPIR.

With the advent of CAPIR-type systems, it has become possible for analysts with no formal photogrammetric training (e.g., biologists, foresters, planners, etc.) to be directly involved in developing and exploiting digital databases.

Based on prior Autometric, U.S. Fish and Wildlife Service and in-house USAETL efforts, USAETL (ETL) is performing work under the Corps' Surveying and Satellite Applications/Remote Sensing research program to evaluate, demonstrate and document the potential of CAPIR technology for Civil Works data extraction, database development and database updating applications. As part of this effort, a contract was awarded to Autometric, Inc. to assess potential Civil Works and Military applications and to plan and conduct experiments to demonstrate possible uses of this technology.

1.2   Summary

This Guide is intended to give the user a general overview of the use of the APPS-IV/CAPIR system. The system hardware and software is introduced in Section 2.1, and the two major components are described in Section 2.2 - "the APPS-IV" and Section 2.3 - "AUTOGIS."

The APPS-IV is a medium accuracy stereoplotter used for aerotriangulation and mensuration from stereo photography or other projective type imagery. The most notable enhancements to the instrument are the optical system, which enables 6-to 36-

power zoom capabilities, and graphics superposition, which enables the display of digital data on top of the photo model.

AUTOGIS is generally used for collecting data to create and manipulate a digital database. The first step is the digitizing of the outlines of various features (e.g., buildings, forest areas, wetlands, flood plains, etc.) and storing these data on a magnetic tape or disk. All data collection is controlled by Analytical Mapping System (AMS) software.

If the information to be digitized is a form of aerial photography, the system's aerotriangulation capabilities are needed to establish photogrammetric control. Most aerial photography, including frame, panoramic and some types of radar images, can be triangulated using the APPS-IV. This can produce a very accurate digitizing capability (depending on control accuracy), which allows accurate outputs conforming to National Map Accuracy Standards. Up to 10 frames of frame aerial photography can be triangulated (in either strip or block format), digitized, and overlaid onto a U.S. Geological Survey quadrangle with little or no distortion.

The digitizing process in AMS is structured in an arc/node format. In an arc/node structure, the nodes represent the end points (and intersection points) of the arcs. The arcs represent the actual outlines of the feature being digitized. The three modes of digitizing are point, line, and polygon. These enable the data collection of individual points, long straight segments (e.g.,roads or railroads), gentle curves, and irregular features.

After data collection (digitization), AMS provides edit and verification capabilities. Spatial verification provides an automatic check of the digital data for topological validity. The data are then stored in the AMS database from which general reports and plots can be generated.

Once databased in AMS, the data are transferred to the Map Overlay and Statistical System (MOSS) for further exploitation and analysis. MOSS is the portion of AUTOGIS software where these data can be analyzed. Specific functions in MOSS enable the operator to generate reports and statistics (including histograms), change scales, overlay maps, and produce multicolor hardcopy plots.

An important feature of MOSS is its capability to produce cartographic manuscripts (line, point and type fonts are available) that meet National Map Accuracy Standards (if control input is sufficiently accurate). These maps can be labeled accordingly and, with legend capabilities in MOSS, become final output maps for display or reports.

This report also briefly discusses one military and two civil works demonstrations performed by Autometric, Incorporated for the Corps of Engineers ETL facility at Fort Belvoir, Virginia. Other potential applications are also briefly addressed.

Lastly, Section 5.0 lists various references and texts used in preparing this report. Appendix A provides a brief discussion of AMS photogrammetric principles o aerotriangulation. Appendix B shows a sample camera calibration report, and Appendix C contains a list and description of MOSS functions and commands.

2.0   COMPUTER-ASSISTED PHOTOINTERPRETATION RESEARCH (CAPIR)

2.1   System Overview

A basic CAPIR-type system needs the various components shown in Figure 1 to be practical and useful for the types of data collection, analyses and displays for which it is designed.

2.1.1   CAPIR Hardware

The ETL CAPIR system hardware consists of a host computer with storage and display peripheral components, the APPS-IV analytical stereoplotter with graphics superposition, and an X-Y digitizing table.

This system is supported by a Data General Eclipse S/250 minicomputer with an integral array processor. The standard peripherals include 800 and 1600 bpi magnetic tape drives, a 192 mega byte disk, a system console, a printer, and a Versatec electrostatic plotter that provides high-speed, hardcopy graphics.

The monoscopic workstation consists of a commercial 36" x 48" table-mounted, back-lighted, digital tablet. An alphanumeric CRT and a graphics CRT allow for the input of commands and data displays. A special purpose "black box" has been interfaced between the RS-232c output of the table and the RS-232c port of the host computer, so that signals originating from the X-Y digitizing table can be reformatted, buffered and transmitted, to mimic the signals generated by the APPS-IV.

The stereoscopic workstation consists of the APPS-IV analytical stereoplotter manufactured by Autometric, Inc. This station also has an alphanumeric CRT for command inputs and a graphics CRT for display of digitized features. The APPS-IV is discussed in detail in Section 2.2.

A voice recognition unit is currently being integrated into the ETL CAPIR system so that the operator can communicate with the host from either the APPS-IV or the X-Y table and still maintain visual contact, as well as stereo-vision (if using the APPS-IV), with the manuscript being digitized.
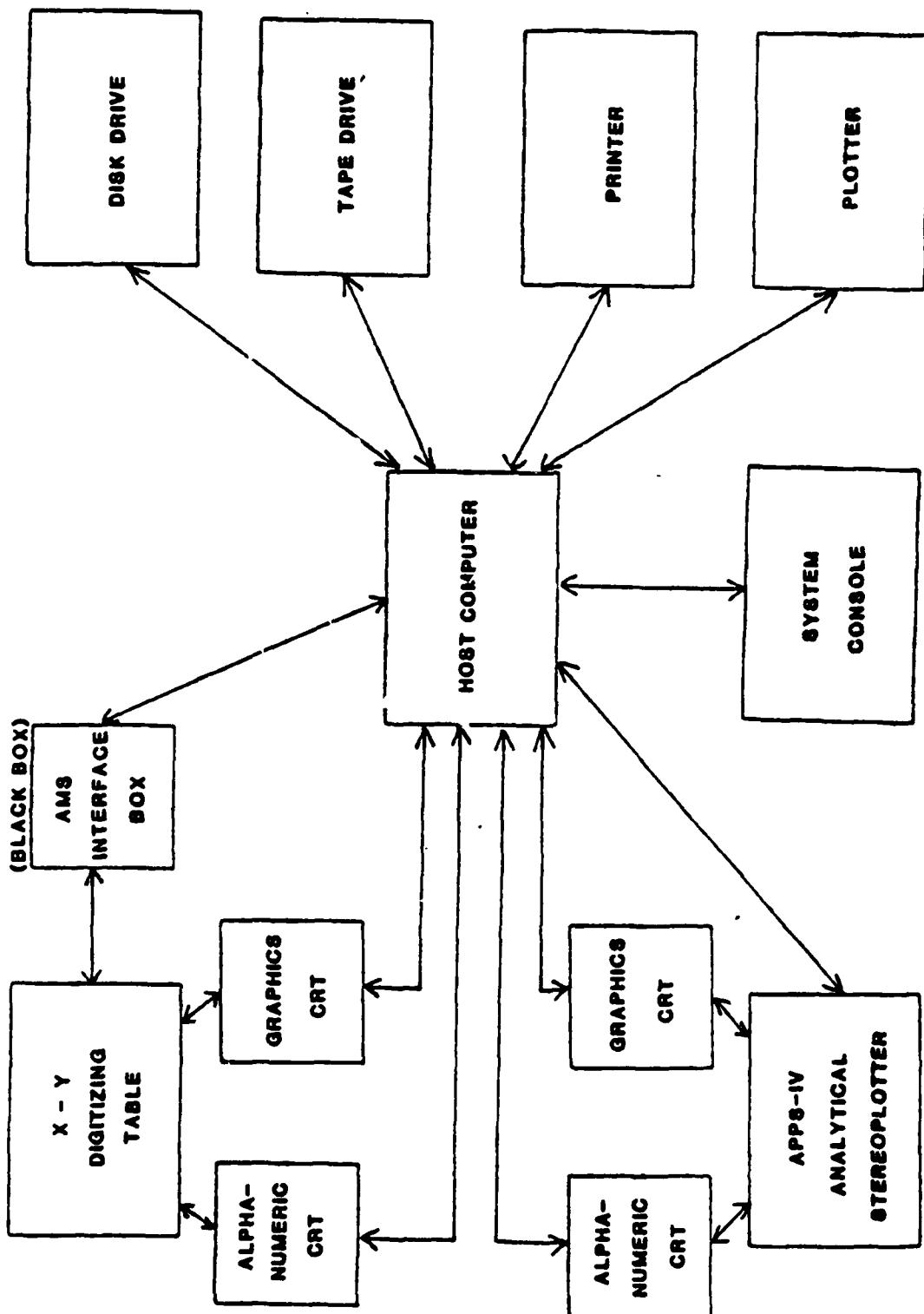
Figure 1 - Basic CAPIR System Components

2.1.2   CAPIR Software

The CAPIR software system consists of the host computer's software and the AUTOGIS geographic information system software. The host software operates under the Data General Advanced Operating System (AOS). It provides a multi-user, multi-tasking environment. System libraries consist of the International Mathematical and Statistics Library (IMSL), high-level array processing software, and graphics routines for Calcomp, Imlac, Tektronix and Versatec devices. Supported compilers include FORTRAN V, Pascal and assembly language. The AUTOGIS and APPS-IV software have also been converted to the DEC PDP 11/70 minicomputer format.

2.2   The APPS-IV

The APPS-IV (Figure 2) is a medium accuracy ($\pm$ 10 microns) analytical stereoplotter, consisting of an optical system for viewing stereo photographs, an electronics system consisting of microprocessors, and a mechanical system with a unique stage-on-stage design. The system's configuration permits significant compactness as compared to other instruments of similar accuracy. The accuracy specification on the stage position is 10 microns after conversion using an affine transformation. However, actual calibration tests have shown the RMS error seldom exceeds 7 microns. Thirteen microprocessors perform all servo motor functions for stage positioning, communications with the host computer and stereomodel maintenance. The instrument, which can accommodate photography (or imagery) with formats up to nine by nine inches, provides controls for manual positioning of the stages, collecting measurements and changing system functions.

2.2.1   APPS-IV Controls

There are three ways of effecting stage movements using the APPS-IV. A disengage switch (or declutch button) allows gross common stage movement. Fine common stage movements are accomplished by use of the trackball. Neither of these controls will affect stereo setup of the model. The x and y thumbwheels are used for removing x and y parallax in the stereomodel and independently move only the upper stages. Data collection is accomplished through the use of a foot pedal.
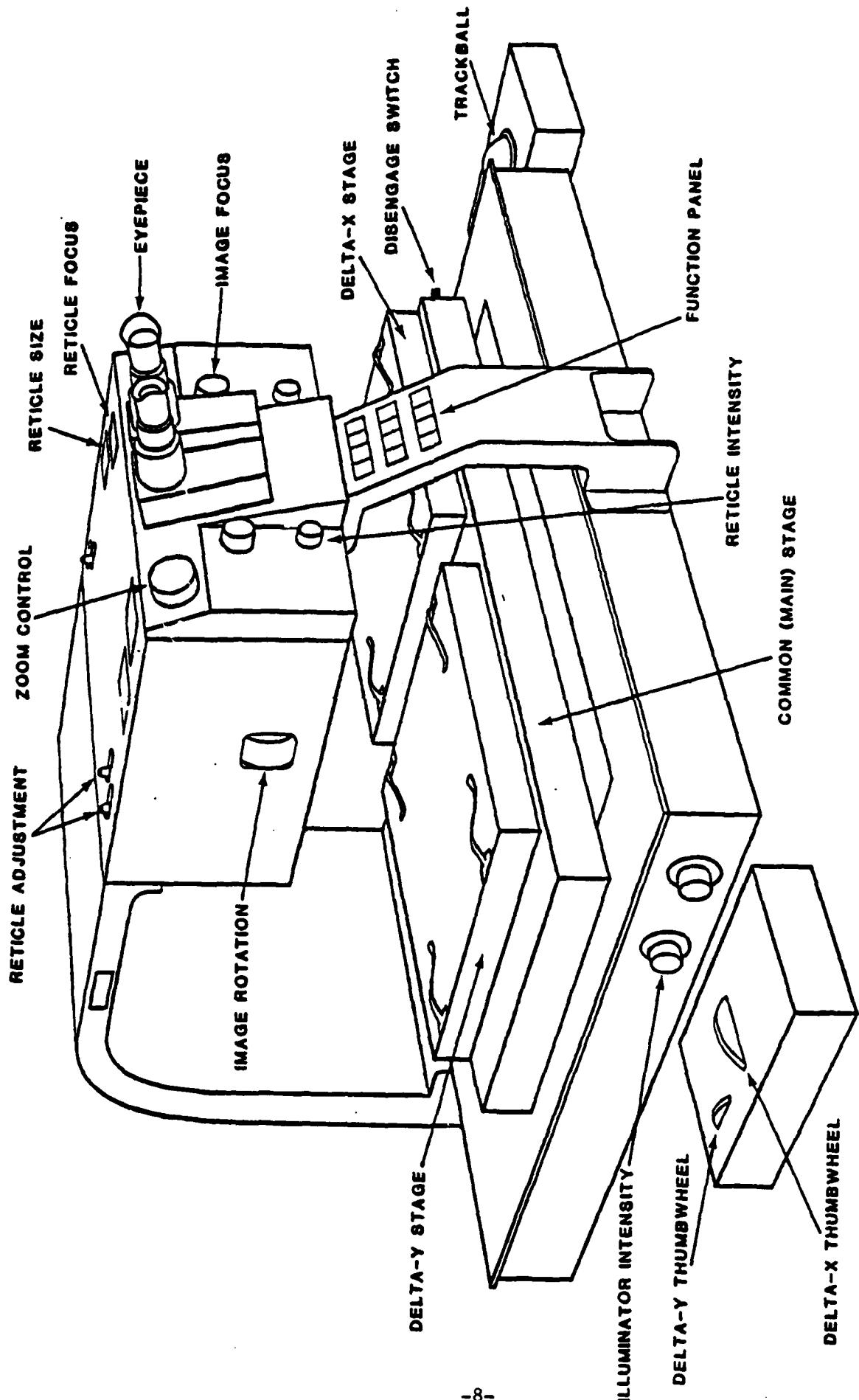
Figure 2 - APPS-IV Analytical Stereoplotter

RETICLE SIZE
RETICLE FOCUS
EYEPIECE
IMAGE FOCUS
DELTA-X STAGE
DISENGAGE SWITCH
TRACKBALL
FUNCTION PANEL
RETICLE INTENSITY
COMMON (MAIN) STAGE
RETICLE ADJUSTMENT
ZOOM CONTROL
IMAGE ROTATION
DELTA-Y STAGE
ILLUMINATOR INTENSITY
DELTA-Y THUMBWHEEL
DELTA-X THUMBWHEEL

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The function panel controls the major digitizing functions (digitizing mode, node selection, and certain edit capabilities), as well as informs the operator of system error status. The on-line/off-line capabilities are also controlled through the function panel.

2.2.2 Optical System

One of the more notable features of the APPS-IV is its optical system. The Model 3500 OEM Zoom Stereoscope is used as standard optics (Figure 3). The system's 6- to 36-power zoom range is capable of high contrast resolution in excess of 250 line pairs per millimeter at 36 power. Controls are provided for image rotation and y-phoria correction, as well as an illuminated reticle projection system with 10-, 25-, 50-, and 100- micron dot sizes included for measurement purposes. As an option the Model 3500 optics can be equipped with one-half power parfocal demagnifiers on the objective to decrease the zoom range to 3- to 18-power. This range may be more suitable for many photo-interpretation purposes. The field of view is 30 mm or 180 mm, divided by the magnification, whichever is smallest. The field of view is doubled when the one-half power demagnifiers are installed.

2.2.3 Graphics Superposition

The most significant enhancement made to the APPS-IV instrument for the CAPIR system is the development of graphics superposition. Both single and dual optical path superpositions are now available. Graphics superposition provides the capability to view graphics from a stroke-refresh type of CRT optically superimposed onto a stereo model. Graphics superposition is accomplished through a second input channel at the objective end of the Model 3500 stereoscope. The digitized information is beam split into the optical path of the stereoscope (see Figure 3) and superimposed on the stereo-model.

An additional microprocessor is added to the APPS-IV electronics package for each optical axis equipped with graphics superposition. These microprocessors constantly monitor the stage positions and translate the image of the graphics to match the current position of the stage, keeping the graphics registered with the imagery. The geographic coordinates are transformed into image coordinates as they are downloaded from the host computer to the APPS-IV.

Figure 3 – APPS-IV Optics & Graphics Superposition

Labels in figure: GRAPHIC CRT, BEAM SPLITTER, RETICLE BEAM SPLITTER, PHOTO PLANE, 1/2x DEMAGNIFIER, PECHAN PRISM (IMAGE ROTATOR), PINHOLE TURRET, PINHOLE LAMP, ZOOM, PHORIA CORRECTION PLATE, EYEPIECE
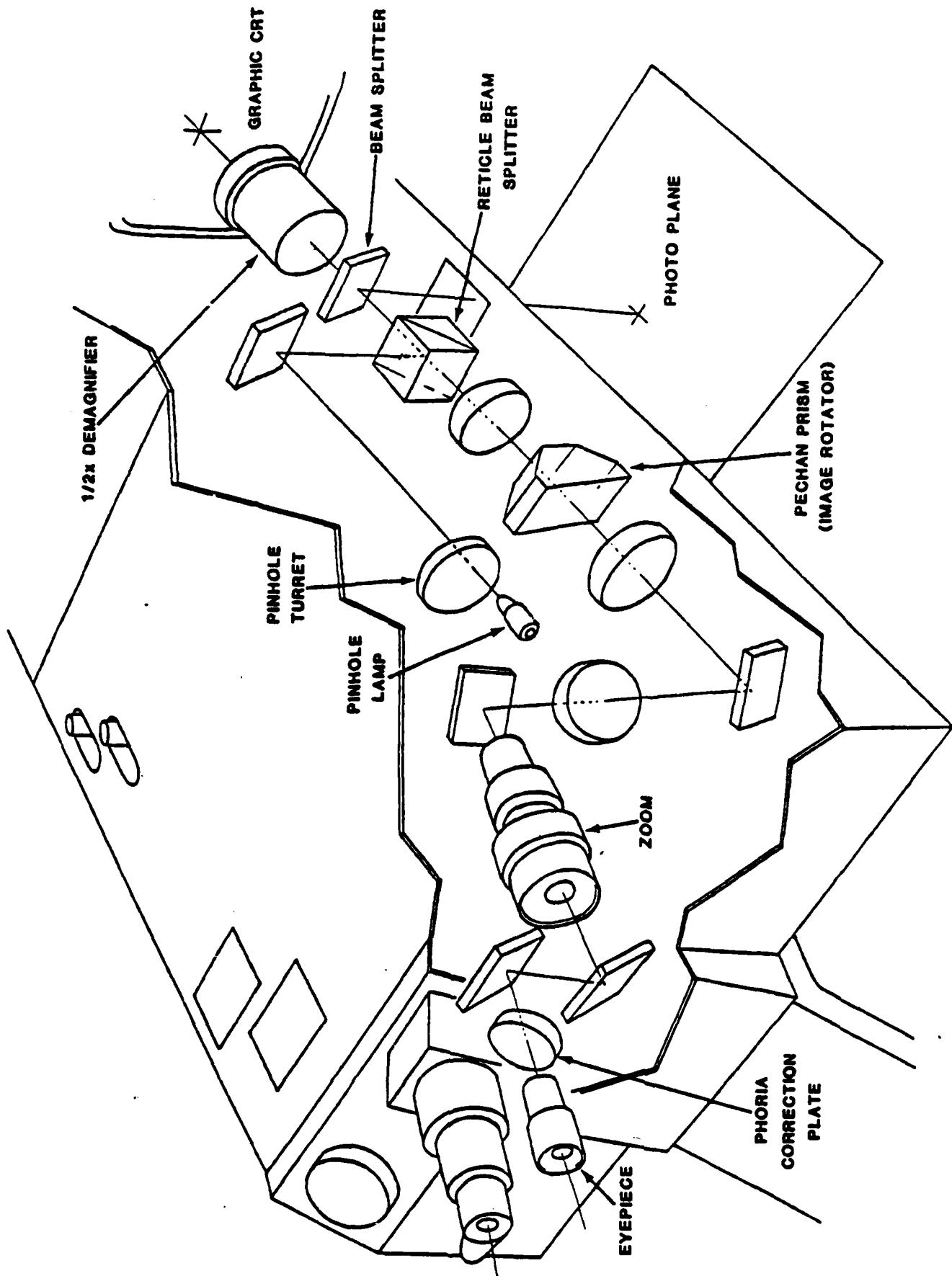
An option with graphics superposition is the one-half power demagnifier referred to above which essentially doubles the resolution of the graphics display lines. When superimposed on the imagery, these lines yield a higher resolution graphic display than would normally be possible by viewing the CRT one-to-one with the imagery.

2.3 AUTOGIS

Digital data from the APPS-IV are collected and manipulated through associated software called AUTOGIS. Using AUTOGIS, photographs or images can be registered to ground control points through its aerotriangulation capabilities. This system can also plot the data at various scales and in various projections. Because of the aerotriangulation capabilities, relatively accurate areal and lineal measurements can be made. Digitized areas can be coded pertaining to the users needs, and individual maps can be overlaid to form one composite manuscript. Since information is stored in a digital format, the database is easily accessible, and the information easily edited. AUTOGIS is divided into two distinct software components. The Analytical Mapping System (AMS) handles the initial data setup and digitization procedures. The Map Overlay and Statistical System (MOSS) handles statistics generation, data manipulation, and output.

2.3.1 AMS Software

The four primary capabilities of AMS consist of analytical aerotriangulation, digitization, spatial verification, and database management.

2.3.1.1 The Aerotriangulation Subsystem

An interactive aerotriangulation package, which embodies many of the principles described in Appendix A, is used to compute the camera station parameters for aerial photographs used for digitization. The main photogrammetric component of this subsystem is the APPS-IV, which is used as a stereocomparator in performing the aerotriangulation.

Using ground control derived from field survey data or topographic map sheets, and photo coordinates measured on the APPS-IV, a rigorous bundle adjustment program solves for camera station parameters (position and attitude) for up to ten frames. The

inputs to this triangulation package are:

(1) Camera parameters
(2) Ground control measurements
(3) Image measurements
(4) Frame estimates
(5) Pass point estimates

Outputs from this package are:

(1) Final frame position, attitude and residuals
(2) Final control point positions and residuals
(3) Final pass point positions and residuals
(4) Error propagation results

The operator is led through the triangulation procedure by a sequence of menus that feature capabilities for APPS-IV model setup (interior orientation), point measurement, on-line data inspections and editing, analysis of triangulation results, and process control.

The solution part of the aerotriangulation subsystem gives the operator complete control of the solution process (e.g., local coordinate system origin selection, number of iterations, etc.). The results of the triangulation solution are used by the APPS-IV for stereomaintenance (loop-close) support of the digitizing subsystem.

Both metric and non-metric cameras (e.g., the Hasselblad 500-EL) have been successfully triangulated using AMS software. A single-model triangulation program, which was developed for the panoramic optical bar camera system, makes it possible to digitize from this source also.

2.3.1.2   The Digitizing Subsystem

The digitizing subsystem in AMS enables the operator to digitize from aerial photographs and map sheets. Photographs and maps at any scale or orientation can be

digitized. This subsystem is menu-driven and guides the operator through the digitizing process.

2.3.1.2.1 The Geounit

The basic digitizing unit in AMS is the geounit. The geounit is an area keyed exactly to the U. S. Geological Survey (U.S.G.S) 7.5 minute, 15 minute, 0.5 x 1 degree, or 1 x 2 degree quadrangle sheets. The user may also select a unique geounit of almost any size by defining the corner coordinates of the specific area. The center of any geounit acts as a unique identifier for that particular area.

2.3.1.2.2 Digitizing Structure

The AMS system produces three basic elements of information during the digitizing process: arcs, nodes and attributes. Figure 4 shows the three different feature types (polygons, lines, and points) formed by these elements. Polygons A and B are delineated on the outside by arcs 1 and 3 for A and B, respectively. Arc 2 (which is also lineal feature C) represents the common boundary. Feature D is a point feature. Nodes a, b, and c represent the beginning and end points of the arcs. All arcs must intersect at nodes. Attributes are the identifiers attached to features during the digitizing process. Each unique feature or group of features should be defined by a different attribute. This enables plotting of features by individual attribute later on in MOSS. To illustrate the significance of attributes, consider that arc 3 is digitized from node a to b to c. In this case, feature A is on the right and B on the left. Therefore, arc 3 has a left attribute of B, a right attribute of A, and a center attribute of C. Feature Z is a polygon and is the background feature for the manuscript.

2.3.1.2.3 Digitizing Modes

There are three different modes of digitizing in AMS: point, curve, and stream. In point mode, the discrete points that delineate the feature are identified by the operator. This procedure is generally used for straight lines or individual point features. Curve mode is similar to point mode in the manner in which points are chosen. However, cubic curves are fitted between the points instead of straight lines.
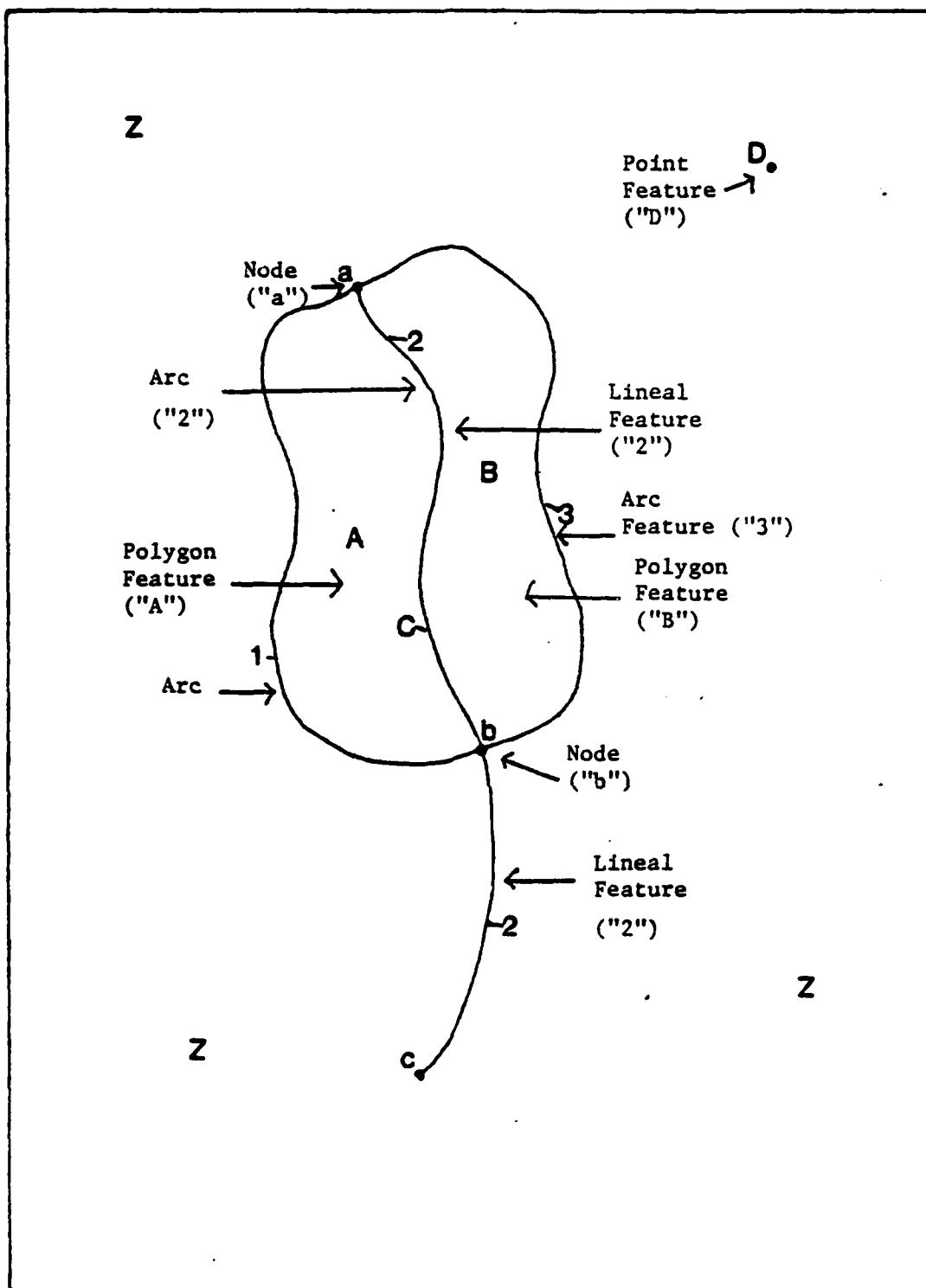
Figure 4 - AMS Feature Types

This mode is useful when the features being digitized are characterized by gently curving lines. Stream mode is used for digitizing intricate, irregular features. In this mode, points are recorded automatically at a specific distance interval as the feature is traced.

2.3.1.2.4   Edit Capabilities

The editing of data can occur at two different times during the digitizing process. One, if a mistake is made while an arc is being digitized, the operator can delete the entire arc from the data set and digitize the arc again or, alternatively, the end portion of that arc can be "clipped off" and digitizing continued normally. A second edit procedure lets the operator identify a specific arc, node, or polygon by its ID number and perform the required edits to correct any data set containing errors.

2.3.1.3   Spatial Verification

As actual features are formed during the digitizing process, the information needed to form a topologically valid data structure exists upon completion of digitization. When the digitizing for a geounit theme has been completed, a data verification process is performed. In this process the data are checked automatically for topological validity. This intra-map verification procedure checks for various errors made while digitizing.The main purpose of the verification program is to determine whether all polygons are closed. Some of the conditions checked during this procedure include:

(1)   Illegal attributes
(2)   Missing attributes
(3)   Missing nodes
(4)   Illegal arcs
(5)   Missing arcs
(6)   Duplicate arcs
(7)   Kinks within an arc
(8)   Spikes (overshoots)
(9)   Gaps

When completed successfully, the verification procedure confirms that a topologically valid manuscript has been compiled.

2.3.1.4   The Database

The AMS geographic database has a simple structure due to the use of the "geounit" as the functional division of information. The geounit structure is formatted in the same manner as the U.S.G.S. topographic map series index map; that is, the individual quadrangle maps are equivalent to geounits.

The database subsystem includes two types of database structures: national and project. The national database covers the conterminous United States and consists of four geounit sizes:

(1)   7.5 minutes x 7.5 minutes (1:24,000)

(2)   15 minutes x 15 minutes (1:62,500)

(3)   0.5 degrees x 1 degree (1:100,000)

(4)   1 degree x 2 degrees (1:250,000)

These geounit sizes are equivalent to the four standard U.S.G.S. quadrangle sizes. The project database can cover an area as small as 2 seconds by 2 seconds or as large as one quadrant of the earth's surface. The project database is designed completely to user specifications through the use of an interactive program.

Any geounit stored in the database can be queried or plotted. The queries provide statistical summaries describing the type, quantity and area of features on a geounit basis. In the database function, the user can create projects, themes and classification schemes needed for subsequent analysis. The database function also serves as the bookkeeping section of AMS.

2.3.2   MOSS Software

Once a map or photograph has been digitized and verified, it is then transferred to the MOSS database in a form suitable for quick and efficient retrieval, analysis and display. During the transfer process, the coordinate data are transformed from latitude-longitude coordinates to UTM, Lambert Conformal, Polyconic or Albers coordinates for the actual data analysis. This transformation process converts the coordinate data from an arc-second format to a metric format so that computational and other analytical efforts are more efficient and understandable to the system user.

MOSS is an extensive, completely interactive software system that enables the user to execute over 70 different functions (Appendix C). Each function is finite and performs a particular task, such as plotting a map on the CRT. MOSS is not a model and makes no a priori assumptions about what the user wishes to do. These different functions are subdivided into five main groups (Table 1):

     (1)   General purpose functions

     (2)   Database functions

     (3)   Analysis functions

     (4)   Display functions

     (5)   Spatial retrieval functions

The user utilizes a simple, English type command language to execute these functions. Since MOSS is interactive, the user executes these functions while seated in front of a terminal.

2.3.2.1   General Purpose Functions

General Purpose Functions perform no data manipulation. These functions enable the user to erase the screen, print a table showing the cost of a MOSS session, or terminate a MOSS session. These functions are easily understood and require no technical or analytical training.

2.3.2.2   Database Functions

Database Functions enable the user to manipulate data stored in the MOSS map database. The user may be connected to three map databases simultaneously. One of these databases is called the master map database and contains the original digitized map data. The second database stores raster (or cell) data (in three dimensional format), and the third database stores point, line, and polygon data (in two dimensional format). These user "work" databases usually contain the results of some map analysis or manipulation, such as polygon overlay. Users may retrieve, store, and/or delete maps from their "work" databases, as needed.

Table 1 - MOSS Functions/Commands

NOTE: A description of these functions and commands can be found in Appendix (C).

General Purpose	Database	Analysis	Display	Spatial Retrieval
AUDIT	ACTIVE	AREA	ASSIGN	CONTIGUITY
BAUD	ADD	ASPECT	BLOWUP	EDGE
CLI	ATTRIBUTE	BUFFER	CALCOMP	PROXIMITY
COST	BSEARCH	CBUFFER	CELLPLOT	SIZE
DEBUG	DELETE	COMPOSITE	ERASE	
FINISH	DUMP	CONTOUR	LEGEND	
HELP	EDITATT	DISTANCE	LINE	
LOCATE	EXPORT	FREQUENCY	NUMBER	
NEWS	FREE	GRID	PLOT	
QUERY	LIST	LENGTH	PROJECTION	
	MERGE	LPOVER	RESET	
	MULTIVAL	MODELG	SHAPE	
	OPEN	OVERLAY	SYMBOL	
	POLYCELL	PERIMETER	TESTGRID	
	RASTER	POINTOVER	THREED	
	REPORT	PROFILE	WINDOW	
	SAMPLE	SLOPE	WRITE	
	SAVE	STATISTICS		
	SELECT			
	SNGVAL			
	SPSS			
	STATUS			
	STUDYAREA			
	TEXT			
	TRANSLATE			
	WEED			

A map database can contain up to 2,000 maps. Each map can contain up to 16,000 polygons, and each polygon can have up to 32,000 coordinate pairs and 225 islands. Each map can also have up to 800 attribute types (such as vegetation type). In addition, the user can store up to 200 minor attributes for any point, line, or polygon.

Once map data are stored in the database, the user may perform any of the following database manipulations:

(1)   Obtain a list of maps
(2)   Obtain a list of legends for a map
(3)   Obtain a list of subjects for a map
(4)   Obtain a list of polygons
(5)   Select data from a map
(6)   Save a map in user work database
(7)   Merge maps
(8)   Archive and de-archive maps to and from magnetic tape
(9)   Determine the status of a map

In addition to these functions, there is a set of database functions that only the database administrator can use. These allow for the insertion, deletion, and update of maps in the master map database.

2.3.2.3   Analysis Functions

The Analysis Functions represent the workhorse functions of MOSS. These functions enable the user to manipulate map data, create new maps, and perform mensuration and statistical analyses. Perhaps the most powerful of the analysis commands is polygon overlay, which enables the user to take the logical intersection between two maps and generate a new map which would be stored in the user's "work" database (Figure 5). Some of the other analysis functions are:

AREA: Produce a table showing areas by polygon type.
DISTANCE:Find the distance between two points.
QUERY: Point to a point, line, or polygon with the
                cursor and identify it.

MAP 1

MAP 2

RESULT
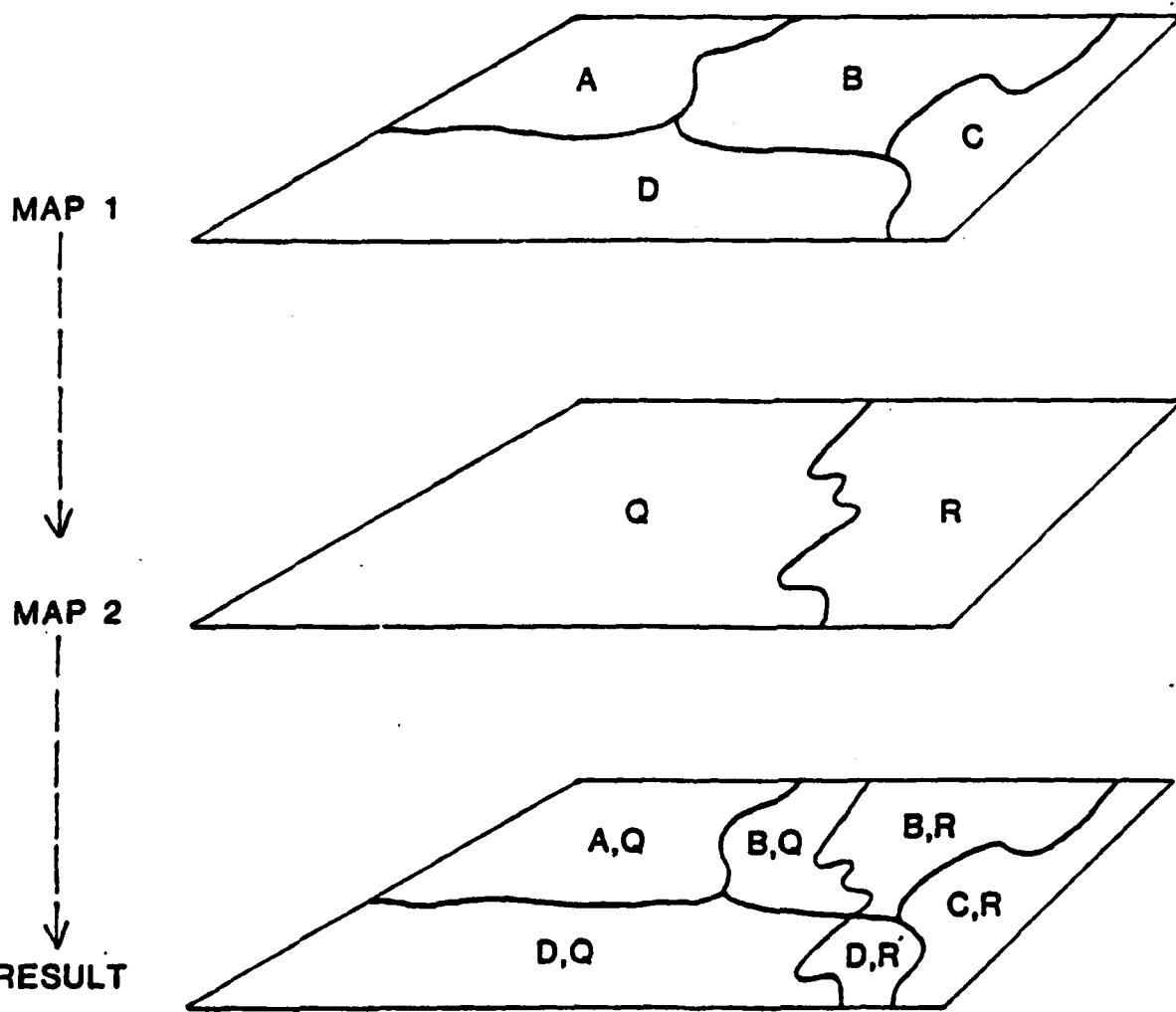
Figure 5 - Polygon Overlay Process

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POLYCELL Perform polygon to cell conversion.

BUFFER: Put a buffer zone around a point, line, or
polygon.

2.3.2.4   Display Functions

Display Functions allow the user to display or plot any map or part of a map stored in any one of the map databases at any one of twenty-one different projections (Table 2). These output displays can often be the final product in a long sequence of analysis steps. Listed below are the uses of four of the display options:

PLOT: Produces a plot of a map on a CRT.

SHADE: Produces a shaded map on a CRT.

THREED: Produces a three-dimensional display of either
raster or elevation data.

CALCOMP: Produces a color map on the plotter.

2.3.2.5   Spatial Retrieval Functions

The Spatial Retrieval Functions are uniquely geographic in nature. They analyze map data on the basis of size and distance criteria. Examples of the four spatial retrieval functions are:

(1) SIZE: "Give me all the elk winter habitat areas that
are greater than 10 acres and less than 100 acres in size."

(2) EDGE: "Calculate and store as a new map all the common
edges between water bodies and proposed strip mine lease
areas."

(3) CONTIGUITY: "Identify the ponderosa pine forest areas adjacent
to ponderosa/pinion juniper forest areas."

(4) PROXIMITY: "Give me all the Federally-owned coal lease areas
that are located within one-quarter mile of a road."

Table 2 AUTOGIS Projections

Projection No.	AUTOGIS Code	Projection
1)	0	GEOGRAPHIC LATITUDE/LONGITUDE
2)	1	UNIVERSAL TRANSVERSE MERCATOR
3)	2	STATE PLANE
4)	3	ALBERS CONICAL EQUAL AREA
5)	4	LAMBERT CONFORMAL CONIC
6)	5	MERCATOR
7)	6	POLAR STEREOGRAPHIC
8)	7	POLYCONIC
9)	8	EQUIDISTANCE CONIC
10)	9	TRANSVESE MERCATOR
11)	10	STEREOGRAPHIC
12)	11	LAMBERT AZIMUTHAL
13)	12	AZIMUTHAL EQUIDISTANCE
14)	13	GNOMONIC
15)	14	ORTHOGRAPIC
16)	15	VERTICAL NEAR SIDE PERSPECTIVE
17)	16	SINUSOIDAL
18)	17	EQUIRECTANGULAR
19)	18	MILLER CYLINDRICAL
20)	19	VAN DER GRINTEN 1
21)	20	OBLIQUE MERCATOR

3.0   APPS–IV/CAPIR SYSTEM CAPABILITIES, PROCEDURES, AND ADVANTAGES

The APPS–IV/CAPIR system is capable of exploiting and manipulating many types of remote sensor data. The following subsections describe some of the major capabilities of this system.

3.1   Major Capabilities

3.1.1   Digitizing Capability

The APPS–IV/CAPIR system is capable of digitizing from maps and photographs at any scale or orientation. Frame photography, panoramic photography, and some types of radar imagery can be digitized using the APPS–IV. A major feature of the digitizing capability is the multiple attributes files. AMS permits multiple overlays (classification schemes) to be digitized simultaneously by assigning multiple attributes to the segments as they are digitized. This eliminates the "coincident line" problem when multiple manuscripts are combined after separate digitizing.

The incorporation of high power and high resolution optics into the APPS–IV system is significant because these capabilities are required for most photo-interpretation tasks, particularly when high resolution, high-altitude imagery is used. The significant advantage is that the operator now has the ability to perform real-time,detailed photointerpretation tasks in the stereomodel during digitization, thus rendering prior light table tasks obsolete. The ability to interpret and record data concurrently is far more efficient than having to interpret and record data in separate steps.

The addition of graphics superposition greatly aids in the digitizing process. Graphics superposition capabilities enable the operator to display previously digitized data on top of a stereomodel. This display could consist of the superposition of previously digitized data on top of newer photography so that updating can be conducted. Or, the display could consist of the data currently being digitized by the operator; this would enable the operator to view the newly-formed lines as they are digitized.

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An option with the APPS-IV is dual graphics superposition in which the operator can view superimposed graphics in stereo (assuming three-dimensional data had been previously digitized). This capability aids the operator in keeping the floating reticle on the ground while digitizing, and also provides a good indication of the accuracy

Edit capabilities within the digitizing subsystem enable the operator to make corrections to an area while digitizing or to make corrections after the entire manuscript is completed. Editing capabilities include addition and deletion of arcs, nodes, and attributes.

Verification capabilities in AMS provide for creation of topologically valid manuscripts, as well as insure that features match along the boundaries of adjacent manuscripts.

3.1.2 Profiling/Contouring

The APPS-IV microprocessors enable the operator to collect profiles in an evenly spaced grid using any designed coordinate system including UTM, local tangent, state plane, or geographics. Once the operator has input profile end points and collection interval, the only task to perform is to keep the floating reticle on the ground while the APPS-IV drives along the profile lines. A digital elevation model (DEM) is created in this manner.

The APPS-IV can also be used to update old digital terrain models, with a minimum of panelling and host processing. For ease in joining manuscripts the profiles can be collected exactly to a join line and stopped. The panelling process removes any biases present at the join line, thus eliminating the operator's concern over what to do about the overlap area and where to cut one model and begin the next. The profiling capability enables available imagery to be used to derive a high resolution, digital terrain model in real time, for a specific local area of interest, without having to rely on coarse continental level models provided by government agencies for general use.

Points collected in a profile array (or as spot elevations) can be used in MOSS to create contour maps. The system can also display this contour data in raster format as a three-dimensional model of the landscape.

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3.1.3   Aerotriangulation and Stereomodel Maintenance (Loop-Close)

One of the major capabilities of the CAPIR system is the aerotriangulation subsystem in AMS. Currently, this subsystem allows triangulation of up to ten photos for frame photography and has a triangulation capability for one type of optical bar panoramic photography. Some radar model capabilities are also available.

Once the triangulation solution is stored in the frame database, the APPS-IV maintains stereomodel control without continuous communications with the host computer. Once the model parameters are downloaded to the instrument, it operates independently of the host computer. The microprocessors monitor stage positions and perform the required computations to update the relative positions of the photo stages.

This capability is important for other uses of the APPS-IV such as point location. Point location can be used in two different forms. First, if the operator wishes to record (or simply display) the latitude, longitude and elevation of a point, the reticle is moved to the point and the information displayed on the CRT. The second form of point location is one in which the operator wishes to drive to a point with known latitude and longitude. Since the APPS-IV will maintain stereo over the entire photomodel, the task of driving to a specified point is easily accomplished.

3.1.4   Database Capabilities

AUTOGIS' database capabilities enable the storing, editing and retrieval of data in both AMS and MOSS. These databases are either automatically created when the operator stores data in them (e.g., in the frame database or master map database) or are created as per user specification (e.g., project database for AMS or MOSS). Once the database is created, the operator can edit the information already there or add new information. These databases are used for data storage or, as in the case of the frame database, are continually accessed whenever a new model is set up on the APPS-IV. Plots and tables can be generated from both AMS and MOSS databases.

3.1.5   Map Design

MOSS contains many routines that can be used for map design and output. Individual maps as well as composite maps can be output to a Calcomp plotter and printed in a variety of colors. Capabilities exist for labeling features and adding legends, scales and titles. These maps can be generated at any scale or projection regardless of the scale or projection of the original inputs.

Softcopy displays, which can be prepared on color graphic CRT's, can also be a valuable aid in the analysis of data. These displays offer an advantage in that a number of different colors and shading patterns, etc., are posssible.

3.1.6   Statistics

The statistical report generation capability can be used to prcduce tables of area statistics (in acres), lengths (in feet or meters), and frequencies for all features within a manuscript. The operator has control over the type of features and range of areas or lengths (minimum and maximum values) to be used in the statirtical analysis. These data can also be displayed in histogram format. With line printer access, the data can be output for inclusion into a report or briefing.

3.2   Procedural Outline

This section provides a brief outline of general procedures and work flow of a typical CAPIR-type project. Figure 6 shows the general information/process flow of a typical project. The following discussion provides a somewhat more detailed description of various subtasks that may need undertaking in a project. This outline is not intended to be all-inclusive, nor need it be followed to the letter. It is a general work flow that should be modified to satisfy specific project needs.

3.2.1   Project Definition

This step is the initiation step in which ideas are outlined, source materials located, and prospective procedures planned. The following steps will need to be accomplished at some time during a project but are not necessarily discussed in order:
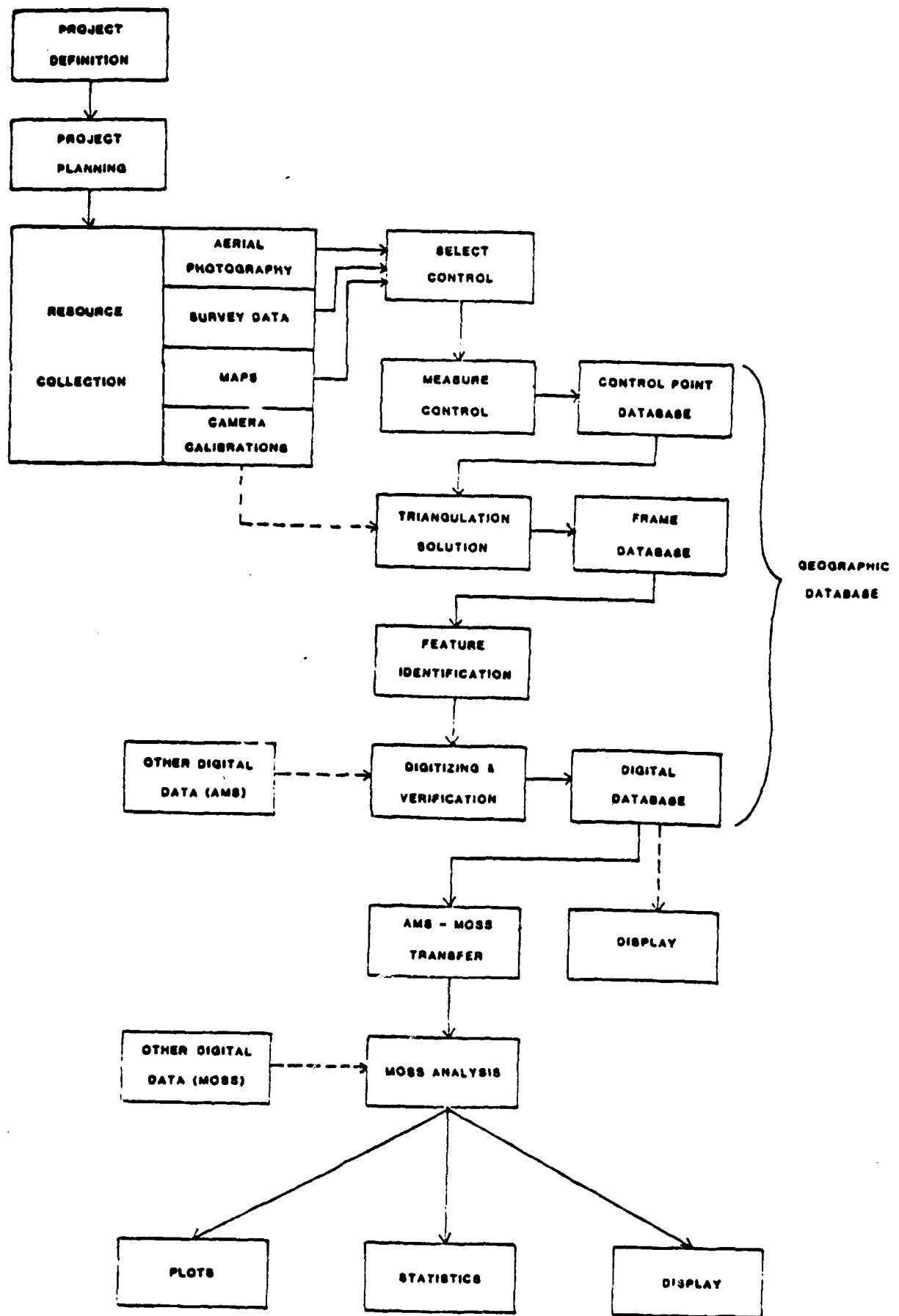
Figure 6 - CAPIR Information/Process Flow

(1) Locate general area of project (i.e., delineate boundaries);

(2) Determine size of project and determine the number of geounit(s) needed;

(3) Locate source information (e.g., photo coverage, camera calibration reports, maps, survey data, digital files, etc.);

(4) Outline requirements for project; and

(5) Determine desired outputs (as far as it is possible at this time), because the kinds of outputs needed may determine how the features should be digitized and how attribute structure should be set up.

3.2.2 Project Planning

This step includes all planning and preliminary work needed before the aerotriangulation procedure begins:

(1) Obtain all source materials (e.g., photographs, calibration reports, maps, survey data, etc.);

(2) Obtain other digital files as needed;

(3) Perform any needed coordinate transformations to convert all coordinate data into geographic coordinates;

(4) Delineate project area on base map;

(5) Prepare photo coverage overlays;

(6) Determine preliminary digitizing (classification) schemes;

(7) Organize data into geounit areas, classification schemes, etc; and

(8) Determine if more data are needed (e.g, additional photo coverage, new field surveys, etc.).

3.2.3 Aerotriangulation

This is a very important step because measurements made here will be carried throughout the entire project. Care must be taken in selecting and measuring ground control points. The steps are as follows:

(1) Select ground control points (or use available survey data);

(2) Delineate ground control points on photography;

(3) Select pass points;

(4) Measure ground control points from map sheet(s) using an X-Y digitizing table;

(5) Enter camera calibrations into camera database;

(6) Enter ground control points into database;

(7) Measure photo control and pass points on APPS-IV;

(8) Perform triangulation solution; and

(9) Enter results into frame database.

3.2.4 Digitization

This is the phase in which working databases are created, data are digitized, and the results stored in the digital database. The steps are as follows:

(1) Determine digitizing categories (i.e., themes, classification schemes, attributes, etc.);

(2) Create user ID's;

(3) Create project ID (i.e., set up geounit(s));

(4) Create themes;

(5) Create classification schemes and assign attributes;

(6) Determine method of digitizing (i.e., plan for placement of arcs and nodes);

(7) Digitize data;

(8) Perform needed edits;

(9) Verify (if more editing needed reverify after edits);

(10) Check final manuscript for attribute placement; and

(11) Enter final verified manuscript into digital database.

3.2.5 AMS to MOSS Data Transfer

This procedure transforms the geographic coordinates used in AMS to UTM, Lambert Conformal, or other projections for use in MOSS, as follows:

(1) Determine new file name; and

(2) Export file from AMS digital database to MOSS database.

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3.2.6   MOSS

MOSS represents the analysis portion of the software and enables the operator to manipulate the data in various ways, as follows:

    (1)   Determine output needs (e.g., plots, statistics, etc.);

    (2)   Perform necessary analysis functions; and

    (3)   Finalize and prepare outputs.

3.3   Advantages of CAPIR

Many advantages exist for using the CAPIR system over other means of extracting, analyzing and manipulating remote sensor data. Digital overlay, scale change accommodation, and database creation are only a few of the advantages of this technology.

3.3.1   Geographic Collection and Storage of Data

One of the major advantages of the CAPIR system is its ability to collect data in geographic coordinates. As the operator digitizes features from a photograph or manuscript, the geographic coordinates (latitude, longitude and elevation) are computed for all points and stored in the database as such. There are two main reasons for digitizing in geographic coordinates:

    (1)   To be able to digitize to the actual edge of a map, in a geographic sense, rather than to a map neat line; and

    (2)   To eliminate a coordinate transformation process when the data are finally stored in the database.

There are also two main reasons for storing points in the database in geographic coordinates:

(1)   A single universal coordinate system must be used if the data are to be continuous between maps without using an unnecessary coordinate transformation or edit function to match the data; and

(2)   Maps can be easily organized in the database according to geographic location. In this manner, one is able to access any map in a fraction of a second. Consequently, large portions of the database can be completed more efficiently.

Although using a geodetic coordinate system should be an important consideration in any geographic database design, it is quite often ignored. The major reason for this is usually the lack of an efficient algorithm to perform the coordinate conversion as digitizing progresses. The algorithm existing in AMS, however, functions in a near real-time manner (approximately 250 points/second).

3.3.2   Concurrent Interpretation/Digitization Capability

A major advantage of the APPS-IV is its concurrent interpretation/digitization capability. The zoom capabilities of the APPS-IV optics enables the operator to interpret and record the information at the same time. These tasks become even more straightforward with the incorporation of graphics superposition into one or both of the optic trains. The advantage of graphics superposition is that the operator can actually see the overlay pattern "float" if the floating reticle is not kept on the ground. This allows more accurate digitization and updating of manuscripts.

3.3.3   Scale and Orientation Differences

The capability of the APPS-IV and the X-Y table to handle photographs and maps at any scale and orientation eliminates the need to enlarge or reduce map sheets before beginning analysis. The materials can be digitized at their original scale and overlaid or displayed at any other scale (using MOSS), thus eliminating inaccuracies inherent in enlargement or reduction processes. This also negates the effects of "shrinkage" and damage to old paper copy maps. These inputs and outputs can also be digitized and displayed in over 20 different projections (see Table 2).

3.3.4   Digital Database Advantages

Since the AUTOGIS database corresponds to the format of U.S. Geological Survey quadrangle sheets, the output can be displayed to overlay exactly with these sheets. Working with only one scale of data makes updating easier. These databases can be updated, manipulated and improved without destroying the original data. Thus, historical accuracy is achieved and new data can be added without preparing a separate copy of the old data.

Many paper copies showing nearly the same data are often needed in a large organization, depending upon the specific requirements of each department within that organization. With the CAPIR system, and a central database, the entire database is updated as updates are made. Thus, all a department needs is access to a terminal to retrieve the data that pertain to its special requirements. This reduces the amount of storage space needed and labor required to assure that all departments receive the updated manuscripts.

Since the data in the AUTOGIS database are in a digital format, other digital files (e.g., DIME and HEP) can be easily compared and used for analysis, Other current or future remote sensing data stored in digital format (e.g., LANDSAT and SPOT satellite data) can also be integrated and analyzed.

3.3.5   Aerotriangulation

The aerotriangulation ackage accounts for photo distortions to provide accurate mensuration results. This can be very helpful in mapping inaccessible or extremely large areas where field survey crews were previously needed. Since this package is included in AMS to support the digitizing capabilities, no separate distortion calculations or "photo shift" information is needed before beginning data collection or mensuration tasks.

4.0 APPLICATIONS OF CAPIR TECHNOLOGY

CAPIR technology has a potential for supporting a number of Corps functions in planning, management, and engineering. CAPIR's basic capabilities, which consist primarily of the quantification, measurement, encoding, storage and manipulation of remotely sensed imagery, provide a detailed, spatial, geo-encoded, digital geographic database that can be analyzed and processed in numerous ways. Because the CAPIR technology quantifies geographic information in three dimensions, the exact location and orientation of a point, a line, or polygon can be easily determined. This exact photogrammetric positioning capability thus allows further manipulation and analysis. The specific methodologies, techniques, and applications are limited only by the imagination of the user/analyst and the specific requirements of the problem itself.

A number of projects are currently underway at ETL to demonstrate the utility of CAPIR technology to supporting certain Corps activities. Section 4.1 describes three of the most recent efforts. Section 4.2 discusses the potential applications of CAPIR technolgy to other Corps-related functions involving planning, management, engineering, and so forth. Section 4.3 provides a brief discussion of current or past efforts involving CAPIR technology that have been conducted at other government facilities or in private industry.

4.1 USAETL Demonstration Project Summaries

Since 1979 the U.S. Army Engineer Topographic Laboratories (USAETL) has carried out a number of CAPIR projects to further exploit the rapidly-developing areas of analytical photogrammetry, computer-assisted photointerpretation, and geographic information systems. A number of tasks have been conducted to demonstrate, evaluate, and document the potential of CAPIR technology for data extraction, database development, and database updating applications. Two projects (Detroit District/Clinton River and Portland District/Columbia River) were recently conducted to demonstrate CAPIR's utility in supporting Civil Works activities, and a third project (Seattle District/Fort Lewis) was conducted to assess CAPIR's utility in supporting the Corps Military Program efforts. These projects are briefly discussed in the following sections.

4.1.1 Clinton River/Detroit District

The Clinton River project was conducted in conjunction with the Corps Detroit District in order to demonstrate how state-of-the-art analytical photogrammetric equipment and computer-assisted photo interpretation techniques could be used by the Corps to extract and manipulate data required to perform flood damage assessments. Structures (building types) and land use information were interpreted using stereo aerial photography and entered into a digital GIS for comparison and processing with ancillary, raster-formatted information. These data were then analyzed for their suitability for input to such Corps tasks as SID (Structure Inventory for Damage) and DAMCAL (Damage Calculation Program).

4.1.2 Columbia River/Portland District

The second Civil Works project was conducted to demonstrate the utility of CAPIR technology for supporting the Portland District's efforts in monitoring and mapping changes in wetland areas in the Columbia River. The objectives were to utilize temporal aerial photography acquired in 1957, 1974, and 1981 to create a digital database of land cover information by year, to identify and map erosion/accretion rates, and to develop statistical records, by year, of land cover acreages and changes therein. Approximately 12 land cover themes were mapped for each year, and a number of maps and statistical data were developed to show the historical change in the wetland areas.

4.1.3 Fort Lewis/Seattle District

A third project was conducted to demonstrate CAPIR's potential application in supporting the Corps Military Programs efforts. Specifically, CAPIR technology was utilized to create and revise digital data files of the information contained in the Corps' Fort Lewis (Seattle District) Master Plan. Selected land cover information was extracted from 1982 aerial photography and entered into a digital GIS database, along with historical map data contained in the 1967 Master Plan maps, for integration, analysis, manipulation and output. APPS-IV graphics superposition techniques were utilized to overlay historical map data onto the 1982 photography in order to create a revised database showing changes. The effort resulted in the creation of a digital historical map database (for 1967), a second database containing only those features that

had been added or deleted since 1967, and a third database representing the new, updated database. A number of multi-scale, multi thematic maps were prepared for the Fort Lewis area.

4.2 Other Potential Applications of CAPIR Technology in the Corps

The applications of CAPIR system technology to the kinds of projects undertaken by the Corps of Engineers lie in the capability of the system to perform two tasks:

(1) to measure accurately from aerial photography and other types of imagery; and

(2) to integrate and synthesize information from multiple data set sources such as remote sensing systems and thematic maps.

The basic capabilities of CAPIR technology as indicated above provide a multitude of potential and real applications to numerous current and/or future Corps functions in planning, management, operations, construction, engineering, and other areas. Many of these Corps activities would benefit from utilizing CAPIR technology in one or more aspects, although in some cases additional work is needed to fully test, evaluate, and demonstrate the specific application. Some of the more important areas in which CAPIR technology should have direct application are discussed in the following sections.

4.2.1 Watershed Studies

Accurate identification and mensuration of land use and land cover types using the APPS-IV can contribute to more accurate and reliable runoff-infiltration predictions. For example, using the analysis tools of CAPIR, land use types can be synthesized with soil types and slope categories in urbanized watersheds or areas otherwise undergoing rapid change. Baseline studies of land use and land cover can then be updated by visual analysis or by digital analysis of satellite imagery or satellite-acquired digital data.

4.2.2   Erosion/Sedimentation Studies

These studies require the same information elements as are required in watershed analyses - principally soil type, land use, and slope. This information can be derived from existing maps or remote sensing systems. Typically, space-borne imaging systems, such as the Landsat MSS and Thematic Mapper, the SPOT HRV, and the Shuttle LFC, can be used for preliminary estimates covering regional size areas, while medium or large-scale aerial photos would be used for final estimates on smaller areas.

4.2.3   Dam Site Selection

For analysis of the suitability of dam sites and their resulting impoundment basins, many types of information must be identified, measured, mapped, and synthesized with other data, as follows:

(1)   Geologic structure - especially the location of faults and fractures. In mapping conjugate fracture sets, different line symbologies can be selected for portraying compression and extension fractures. Regional structures can be mapped using small-scale imagery, including side-looking radar from SIR-A and SIR-B if possible, followed by the analysis and mensuration of large-scale aerial photos for local structure;

(2)   Lithology - with emphasis on soluble limestone and the location of sink holes and solution channels;

(3)   Measurements of impoundment basin area and volume, including the utilization of digital elevation models;

(4)   Seismic data from published sources; and

(5)   Upstream mapping of soil types, land use/cover, and topography for input to sedimentation estimation procedures.

4.2.4   Corridor Selection

Corridor selection is often necessary for pipeline, power line, and road route planning. After candidate corridors have been selected on the basis of maps and

medium-scale or small-scale imagery, large-scale photography can be interpreted using the APPS-IV and analyzed for the following information:

(1)   cut and fill estimates

(2)   tree counts and size categories for clearing and grubbing estimates

(3)   surficial geologic mapping to locate and quantify borrow materials

(4)   drainage channel mapping and watershed analysis for number and size of culverts.

Using the analysis capabilities of the CAPIR system, all applicable factors can be compared as an aid in selecting the optimum corridor.

4.2.5   Slope Stability Studies

Slope stability studies require elements that have been described under the topics of erosion and dam site studies, including slope steepness, land cover type, soil type, and seismicity. Additional requirements are the potential for oversteepening by stream erosion and for failure due to excess soil moisture. The three relatively constant elements, steepness, land cover, and soil type, can be interpreted and measured on the APPS-IV, and the area under study can be subdivided into units, each composed of a combination of slope, cover, and soil category. Each of these units can be assigned a potential for slope failure based on some critical level of one or more of the time-variable elements: seismicity, soil moisture, and oversteepening.

4.2.6   Applications of Digital Elevation Models (DEMs)

The APPS-IV offers an efficient means of producing digital elevation models (DEM's). Although several other ways of producing DEM's exist, including field surveys and map digitization, digital techniques provide the most effective means of manipulating the masses of data resulting from sensors such as radar or laser altimeters. Further sources of digital elevation information include the digital terrain tapes produced by the Defense Mapping Agency and made available by the National Cartographic Information Center.

Databases resulting from these efforts are well suited not only to the conventional application of automated generation of contour plots, but when properly

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processed, can be utilized to prepare a variety of other end products. Some of the direct applications of DEM's are as follows:

(1) Profile generation - DEM's are often generated by collecting sets of profiles, but mathematical techniques can be used to generate new profiles between any pair of points in the grid;

(2) Determination of intervisibility of points;

(3) Earthwork Calculations - This was one of the first applications of DEM data and is used as a routine procedure by a number of highway departments. The Portland District of the Corps of Engineers has employed this technique for monitoring earth volume for excavation contractor payments; and

(4) Terrain Simulation Using DEM's - Stereopairs can be produced from LANDSAT data to aid in interpretation. The DEM data is used to compute parallaxes which would have been generated in an image made from different exposure stations. The original LANDSAT pixels are then displayed with these parallaxes to produce a simulated stereopair.

4.2.7   Construction Monitoring

Analytical photogrammetry offers special abilities in the monitoring of construction, especially when using terrestrial techniques. Analytical plotters like the APPS-IV can handle nonmetric and convergent photography of any focal length and image format. Analog plotters can rarely reduce these kinds of imagery because of optical-mechanical limitations.

The use of nonmetric cameras offers several attractive advantages over the use of metric cameras. Nonmetric cameras are readily available and relatively inexpensive. They offer a wide focussing range and can be hand held and readily pointed in any direction. These advantages are countered by high distortion, a lack of fiducials, and frequent instability in orientation. A further drawback common to all terrestrial photogrammetry is that atmospheric refraction close to the ground is often unpredictable and is more difficult to model than the atmospheric effects encountered in aerial

photography. Nevertheless, recent research indicates that terrestrial photogrammetry, even using nonmetric cameras, is capable of producing high precision results.

If multiple cameras are used, photogrammetric techniques can capture a "snapshot" of a process and obtain the three dimensional positions of many points at one instant. This technique is frequently useful in monitoring construction projects and measuring structural deformation. Analytical plotters are particularly suitable for this type of work, since they retain the capability of detailed mapping with high accuracy while the rapid model reset capability also makes it feasible to measure the positions of only a few points.

4.2.8   Measurement of Earth Volume

Another engineering application of analytical plotters is in the photogrammetric determination of earth volume. The engineer can use these earth volumes to determine contractor excavation quantity payments (a technique currently used in the Seattle District by the U.S. Army Corps of Engineers and accepted by both contractors and the Government), and in predicting cut and fill quantities. Volume determination is a relatively simple and straightforward process. While the operator keeps the floating dot on the surface of the ground, the APPS-IV automatically drives it along a profile. The resulting set of parallel dense profiles forms an accurate digital elevation model (DEM) of the area. Standard techniques are readily available to compute volumes from a DEM. By comparing volumes from a current DEM with those obtained at an earlier date, an accurate measurement of the amount of earth removed by an excavation contractor can be obtained. The calculation of cut and fill from profile and cross section data is standardized within the engineering industry. Photogrammetric techniques greatly reduce the time and effort needed to obtain the profiles and cross sections with comparable results. Photogrammetric methods are considerably cheaper, easier, and safer than conventional ground surveys.

4.2.9   Verification of Map Accuracy

Another prime use of an analytical plotter like the APPS-IV is the rapid checking of map accuracy. The ability to rapidly reset a model makes the measurement of a relatively small number of points practical. It is easy to envision techniques for measuring a point on a questioned map and having the APPS-IV drive to the point on the

imagery used to produce the map so that the operator can take a static elevation measurement. A number of these measurements could be taken and compared analytically to map measurements. The comparison would rapidly produce an estimate of both the vertical and horizontal accuracy of the map. The ease and efficiency of methods like this allows the use of statistically defensible accuracy references. An APPS-IV interfaced to a standard compilation package could also be used to produce a map, allowing a visual estimation of map accuracy. The use of analytical plotters in standard mapping greatly increases production because of reduced model setup times and the ability to use smaller scale photography while retaining map accuracy.

4.2.10   Survey Applications

Analytical plotters also provide a means to determine the ground position of property corners. If it becomes necessary to stake out a boundary in a remote or inaccessible location, the stages of an APPS-IV could be driven to a desired corner's image on existing photography. The plotter operator could find several identifiable offset points in the area, and the necessary distances and azimuths to the corner could be computed easily. A field party could travel to the area by the easiest method and stake out the corner without having to survey it in over long distances.

4.3   Other Past and Ongoing CAPIR-Type Application Efforts

Several CAPIR-type projects have been conducted by non-Corps Federal agencies, including the U.S. Fish and Wildlife Service, and the Bureau of Reclamation, and by private industry. These projects, which involve such earth resources applications as wetlands mapping, drainage control studies, and geologic mapping, are briefly described below.

4.3.1   U.S. Fish and Wildlife Wetlands Mapping

The U.S. Fish and Wildlife Service's (FWS) Fort Collins, Colorado, office utilizes a CAPIR-type system to develop and maintain a comprehensive geographic data base containing wetlands information. The primary tool used for this effort is the APPS-IV, which provides for detailed photointerpretation of stereo aerial photography covering wetland areas. The data are then entered into a digital data base utilizing AUTOGIS software for storage, analysis, display and output of desired data. A wetlands database

for the entire U.S.A. is being developed at the FWS Fort Collins office.

4.3.2   Bureau of Reclamation

Autometric is currently designing software that will permit the Bureau of Reclamation's Lower Colorado Regional office to set up stereophoto models on the APPS-IV analytical plotter and compile cross-sectional data for a predetermined canal route. The input parameters will consist of information taken directly from a surveyor's field book. The proper transformations from state plane coordinates to geographic coordinates to a local coordinate system are all computed by the software while continuously maintaining a stereomodel (loop-close). The output is specifically designed to be used as input for the Bureau's earthwork program, which will then calculate the required cuts and fills. The output can be designed to be compatible with any earthwork program.

4.3.3   U.S. Geological Survey Study

Autometric, Inc.'s Falls Church office conducted a project for the U.S. Geological Survey in 1981 to investigate the use of side-looking airborne radar (SLAR) and other imagery for resources exploration. The objective was to define the contribution of real and synthetic SLAR to structural geologic mapping and to compare this information with the contributions from three other remote sensing systems. Part of the project consisted of the photointerpretation of stereo aerial photography using the APPS-IV. The desired geological data were then entered into a digital geographic information system and merged with four other sets of data for detailed comparisons, statistical calculations, and thematic map preparation.

5.0   BIBLIOGRAPHY AND REFERENCES

Greve, C.W., 1982. APPS-IV, Improving the Basic Instrument. Photogrammetric
Engineering, 48(6) pp. 903-906.

Howland, J.C., 1982. APPS-IV, Civil Works Data Extraction/Database
Application Study (Phase 1). U.S. Army Engineer Topographic Laboratories, Fort
Belvoir, Va. 117p., ETL-0310, AD-A123889.

Jackson, M., G.R. Hoffman, C.W. Greve and D.L. Ackerman, 1981. A
Parameterization of the ITEK KA-80-A Optical Bar Panoramic Camera System, pp.
477-491. In: Proceedings of the 1981 ASP Fall Technical Meeting. American Society
of Photogrammetry, Falls Church, Va. 629 p.

Leighty, R.D., 1979. Research for Information Extration from Aerial Imagery,
pp. 251-261. In: Proceedings of the Remote Sensing Symposium. U.S. Army
Engineer Topographic Laboratories, Fort Belvoir, Va. 283 p.

Lukes, G.E., 1980. Geographic Data Bases Supporting Scene Generation.
Society of Photo Optical Instrumentation Engineers Journal, Vol. 238, pp. 406-413.

Moffitt, F.H. and E.M. Mikhail, 1981. Photogrammetry. Harper and Row, Inc.,
New York, N.Y. 648 p.

Niedzwiadek, H.A., C.W. Greve, and H.R. Pywell, 1978. The Wetlands Analytical
Mapping System, pp. 320-328. In: Proceedings of the American Society of
Photogrammetry, 44th Annual Meeting. American Society of Photogrammetry,
Falls Church, Va. 440 p.

Reeves, R.G., Ed., 1975. Manual of Remote Sensing. American Society of
Photogrammetry, Falls Church, Va. 2144 p.

Remote Sensing Applications Guide, 1979. Engineer Pamphlet No. 70-1-1.
Department of the Army, Washington, D.C.

Slama, C.C., Ed., 1980. Manual of Photogrammetry (4th Edition). American
Society of Photogrammetry, Falls Church, Va. 1056 p.

Wolf, P.R., 1974. Elements of Photogrammetry. McGraw-Hill, Inc., New York,
N.Y. 562 p.

APPENDIX A

PHOTOGRAMMETRIC CONSIDERATIONS

1.0   PHOTOGRAMMETRIC CONSIDERATIONS

1.1   Types of Imagery

Many types of imagery can be successfully exploited using a
single analytical stereoplotter like the APPS-IV. Current APPS-IV/AUTOGIS
software allows the use of any frame camera system and the optical bar type of
panoramic camera system. The very general math model used internally by the
APPS-IV's microprocessors allows the utilization of any projective camera
system. The two types mentioned above are the only two currently implemented
in the AUTOGIS software package.

1.1.1   The General Camera Model

All types of projective camera models (e.g., frame, panoramic,
and strip) can be reduced to a single common model for use in stereo
maintenance and imagery exploitation. This common model must successfully
approximate all of the following parameters throughout an imaging event:

        (1) Transformation of stage (uncalibrated) coordinates into
             image coordinates and vice versa.

        (2) Elements of interior orientation.
             a. principal point offsets
             b. focal length (principal distance)

        (3) Refinement of image coordinates.
             a. radial lens distortion
             b. atmospheric refraction

        (4) Elements of exterior orientation.
             a. vehicle position
             b. vehicle attitude

In frame camera systems none of these elements are time
variant. In dynamic systems, however, all the elements except focal length
must be considered to be time variant and, over long time periods, non-linear.

A-1

The use of a limited version of the general camera model in the stereoplotter enables the exploitation of most dynamic systems. The general camera model can be stated as:

$$
\begin{bmatrix} x - x_p - Ix \cdot x \\ y - y_p - Iy \cdot y \\ -f \end{bmatrix} = k[M] \cdot \begin{bmatrix} Xg - X \\ Yg - Y \\ Zg - Z \end{bmatrix}
$$

where:

x,y	=	image coordinates of a point
x_p, y_p	=	principal point offset
f	=	focal length
I_x, I_y	=	dynamic axis switches
k	=	scab factor
M	=	ground to photo <u>instantaneous</u> camera orientation matrix, which is a function of camera roll, pitch, and yaw (w, o, k)
X_g, Y_g, Z_g	=	ground point coordinate triplet
X,Y,Z	=	<u>instantaneous</u> vehicle coordinate triplet

This parameterization describes all the projective camera types, which will be further analyzed in the next few sections of this guide.

1.1.2   <u>Frame Cameras</u>

Most aerial mapping cameras in use today can be classified as frame cameras. A frame camera is one in which an entire frame is exposed through a lens that is fixed relative to the focal plane (Figure A-1). The film is held stationary in the focal plane during exposure, or is moved slightly to compensate for image motion.
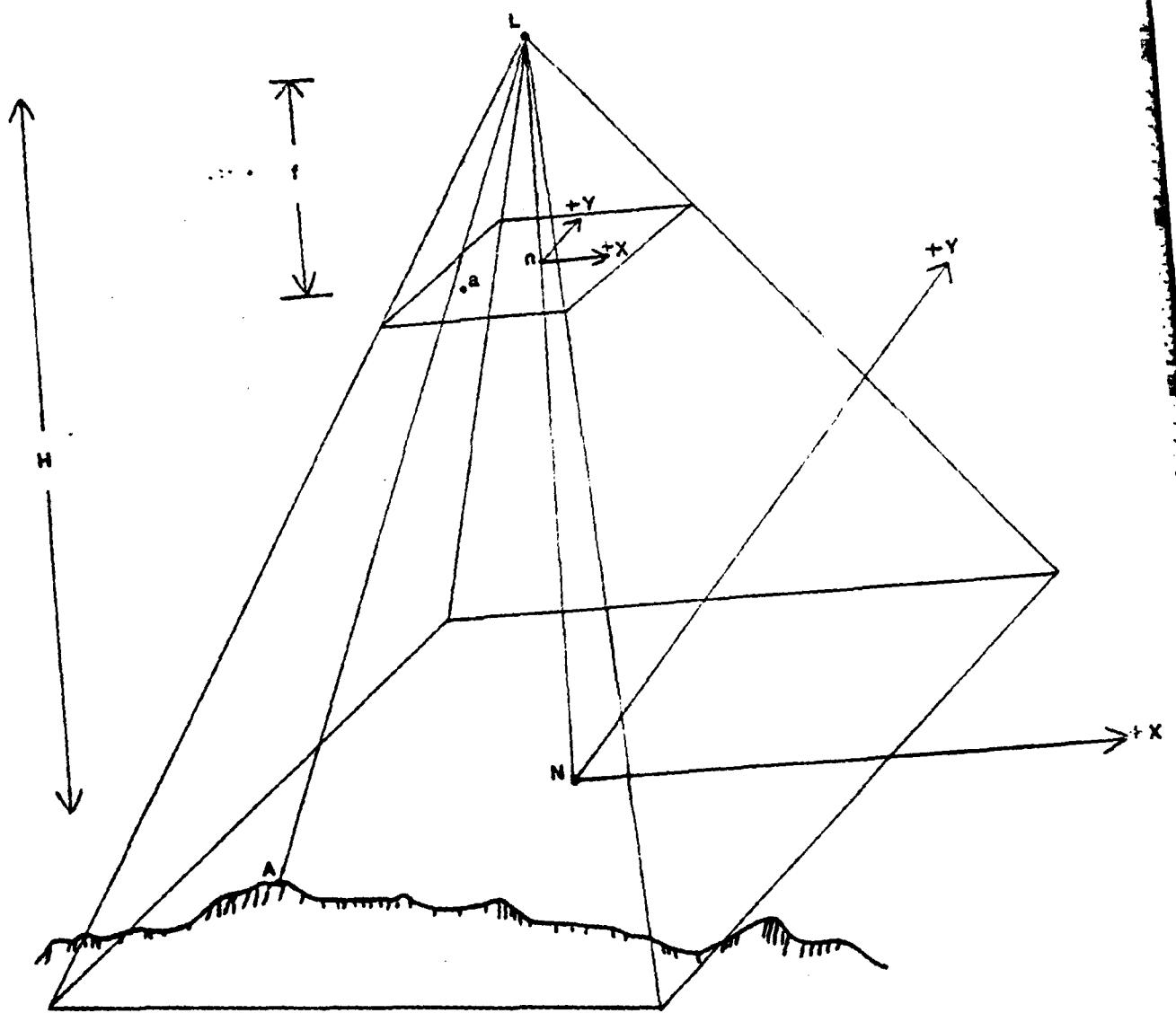
Figure A-1 - The Frame Camera System

A-3

Aerial photographs are exhaustively described in most standard photogrammetric texts, and particularly well in the Manual of Photogrammetry (1980).

Since neither axis of the imaging system in a frame camera is dynamic, I_x and I_y are both set to zero, and the camera model reduces to the standard collinearity equation:

$$
\begin{bmatrix} x - x_p \\ y - y_p \\ - f \end{bmatrix} = k[M] \bullet \begin{bmatrix} X_g - X \\ Y_g - Y \\ Z_g - Z \end{bmatrix}
$$

In a frame implementation of the general camera model, [M] and $[X_g]$ remain constant for a given piece of imagery.

1.1.3   Panoramic Cameras

The panoramic aerial camera is dynamic in a direction normal to the direction of flight. It takes a sweeping picture of the ground, as shown in Figure A-2.

Panoramic cameras were designed in an attempt to combine high resolution and large area coverage in one camera. There are three basic ways of meeting these seemingly incompatible goals:

(1) Narrow angle lenses are used, and only the central portion of the lens is used for imaging.

(2) The lens system scans through large angles across the direction of flight often horizon to horizon.

(3) The film is advanced parallel to the direction of scanning at rates comparable to the ground speed.

Development of panoramic cameras received the impetus primarily from military reconnaissance requirements. The application of panoramic cameras to mapping has been hampered by a difficulty in calibrating such
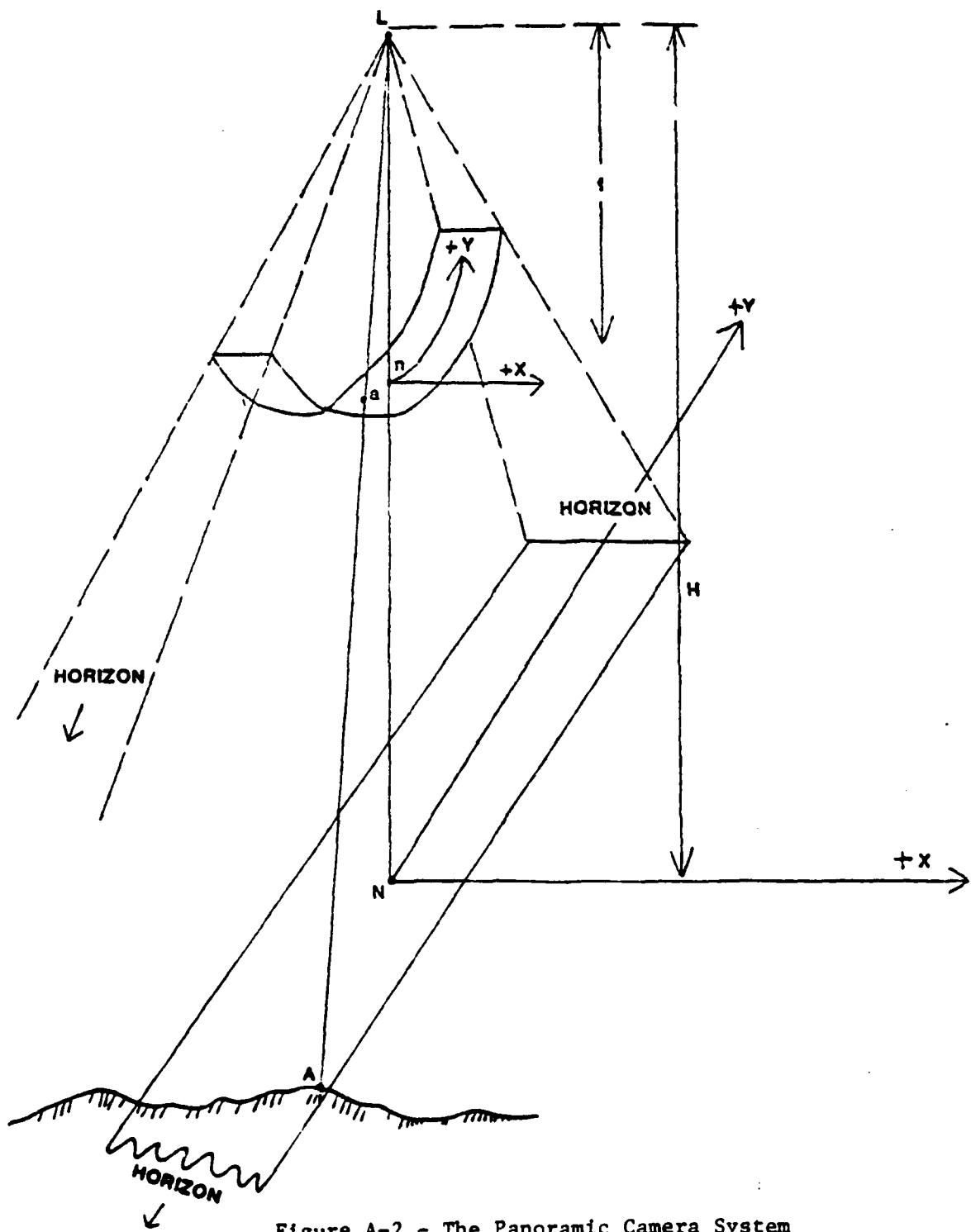
Figure A-2 - The Panoramic Camera System

cameras and by the complicated geometry of the imagery. With the refinement
and increased flexibility of analytical stereoplotters and computers, it is
feasible to fully exploit the high resolution and coverage of the panoramic
camera. The Itek KA-80-A panoramic camera, for example, has been rigorously
modeled and implemented at several installations for use on the APPS-IV.

The dynamic switch setting ($I_x=0$, $I_y=1$) necessary for use of the
panoramic camera system in the general camera model results in:

$$
\begin{bmatrix} x - x_p \\ - y_p \\ - f \end{bmatrix} = k \, [M] \cdot \begin{bmatrix} X_g - X \\ Y_g - Y \\ Z_g - Z \end{bmatrix}
$$

In this implementation, the vehicle position and orientation
parameters are dynamic, that is:

$$w_i = w_o + \dot{w} \cdot t_i$$

$$\phi_i = \phi_o + \dot{\phi} \cdot t_i$$

$$\kappa_i = \kappa_o + \dot{\upsilon} \cdot t_i$$

$$X_i = X_o + \dot{X} \cdot t_i$$

$$Y_i = Y_o + \dot{Y} \cdot t_i$$

$$Z_i = Z_o + \dot{Z} \cdot t_i$$

where:

t_i	=	time of imaging of point i
$(w_o, \phi_o \ldots Z_o)$	=	initial state parameters
$(\dot{w}, \dot{\phi}, \ldots \dot{Z})$	=	angular and positional velocities

Jackson (1981) describes the derivation of these parameters
through aerotriangulation of a panoramic camera stereopair.

1.1.4   Strip Cameras

Strip cameras have not yet been implemented on the APPS-IV, but they are included in this guide because of their successful use in highway and railroad studies, other corridor analysis, and route reconnaissance applications. They also appear to have solid potential in coastline studies. Various future imaging systems (e.g., the French "SPOT" satellite) use a "pushbroom" imaging technique, which is modeled in the same way as strip cameras.

Strip cameras expose a continuous photograph of the underlying terrain by passing the film over a stationary slit in the focal plane of the lens at a speed synchronized with the velocity of the ground image across the focal plane (Figure A-3). In practice, the slit width is usually very small, so that the image of only a narrow striplet of terrain is exposed onto the film. As the aircraft moves forward, a long, continuous photograph results from the successive integration of the narrow striplets.

By setting the switches ($I_x = 1$, $I_y = 0$), the model for a strip camera results in the following:

$$\begin{bmatrix} x_p \\ y - y_p \\ - f \end{bmatrix} = k \, [M] \cdot \begin{bmatrix} X_g - X \\ Y_g - Y \\ Z_g - Z \end{bmatrix}$$

As in the case of the panoramic camera, the vehicle position and orientation factors must be considered as the sum of an initial state and the product of a velocity time multiplication.

1.2   Imaging System Distortions

If everything in this world were perfect, then measurements on a vertical photograph would be directly proportional to the earth's surface (assuming the earth were flat). However, in the real world things are not perfect and distortions enter into the imaging system. On a small project with large tolerances these distortions can be ignored, but for most projects
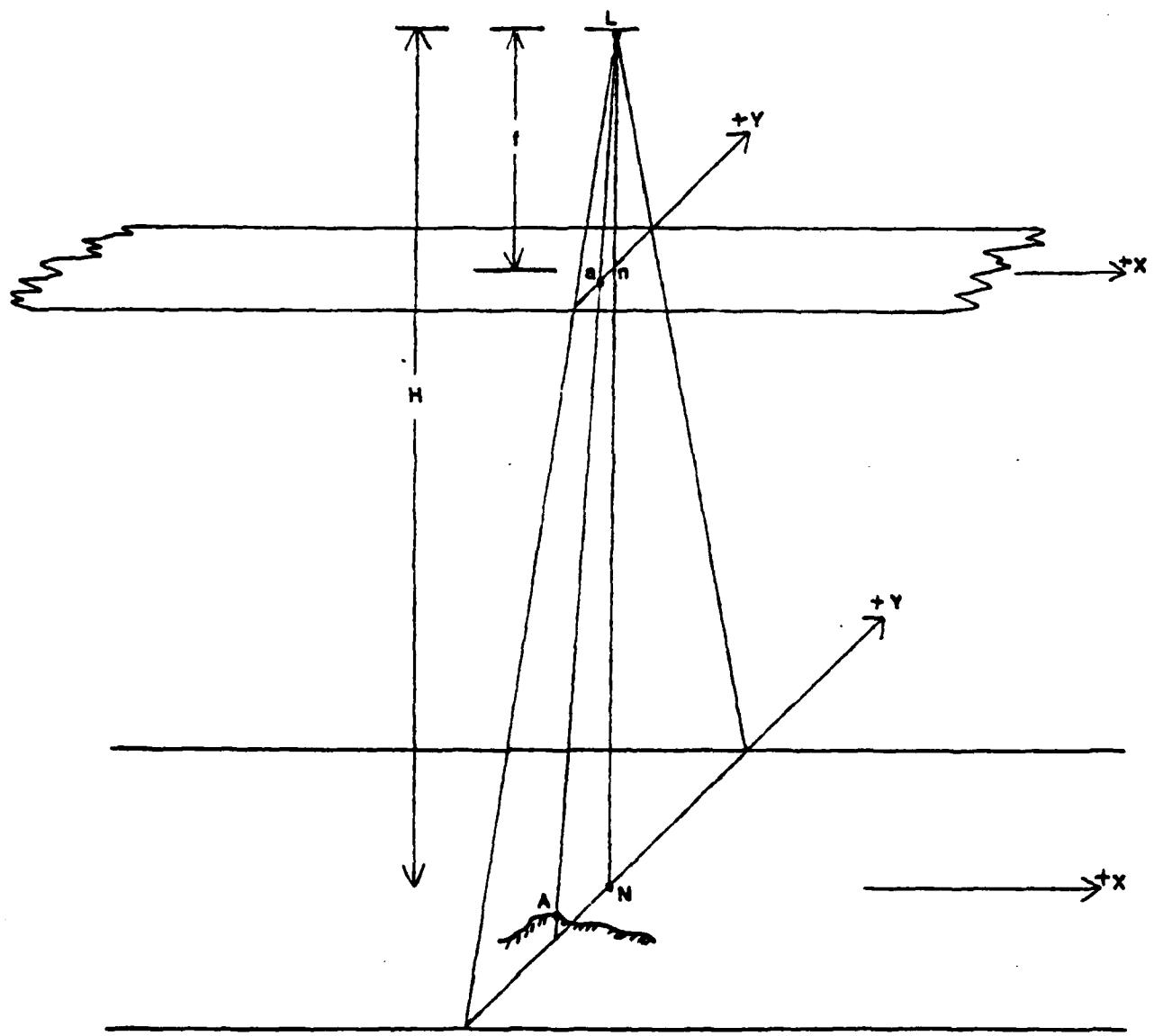
Figure A-3 - The Strip Camera System

these distortions must be taken into account and corrected before any accurate measurements can be made. These distortions originate generally from two sources. Earth curvature and atmospheric refraction originate outside the imaging system while emulsion deformations (film shrinkage), platten flatness, and lens distortions originate from within. These distortions affect the apparent position of a point on the photograph.

1.2.1   Earth Curvature

Earth curvature corrections are not considered in AMS because all the control point inputs are in geodetic coordinates.

1.2.2   Atmospheric Refraction

Atmospheric refraction is ignored in AMS as the distortion is essentially corrected for during the aerotriangulation solution.

1.2.3   Emulsion Determinations

Emulsion deformations or film shrinkage are changes in the photographic material between the time it is exposed in the camera and the time it is measured on a comparator. The basis for this correction is dependent upon the construction and calibration of the camera.

The simplest standard provided by the camera manufacturer is a camera calibration report that gives the measured distance between points (fiducials) iterated along the edge of the exposure format (see Appendix B). A pair of fiducials can be used to compute a linear scale change in that direction (x or y) and is given by:

$$X' = S_x \cdot x$$
$$Y' = S_y \cdot y$$

where: S_x, S_y = calibrated distance/measured distance

X', Y' are true or calibrated values

X , Y are measured values

This distortion is corrected during the interior orientation process by measuring the fiducial marks (see Appendix A, Section 1.4.2).

1.2.4 Platten Flatness

Platten flatness distortions can be considered nearly linear and small enough so that they are ignored in AMS.

1.2.5 Lens Distortions

Lens distortion is defined by the lens designer as the failure of a lens to image a straight line in object space as a straight line in image space and to maintain the same metric. Normally, this distortion is characterized by two distinct components. One is radially symmetric about the principal point (radial distortion), and one is symmetric along a line directed through the principal point (tangential distortion).

1.2.5.1 Radial Distortion

Radial lens distortion can be calibrated in a number of ways. A usual way of offering radial displacement (Δr) to the user is at given intervals of radial distance (R) for a mean for all directions of calibration. For application purposes, a smooth curve is drawn through the data plotted as a function of R, and intermediate values of Δr are interpolated from the graph (Figure A-4). The interval of R for the interpolation is chosen to establish tabular values of Δr such that the increments are:

X, Y = measured coordinates of R

d_x, d_y = individual correction vectors for displacement Δr
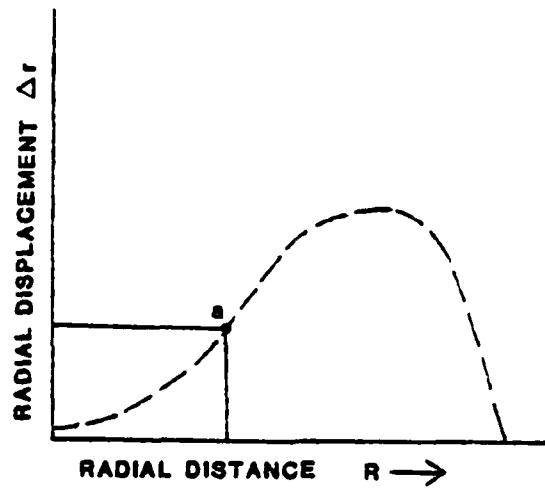
Figure A-4 - Distortion Curve

1.2.5.2   Tangential Distortion

Tangential distortion Δt is a distortion usually due to errors made in assembling the lens so that the centers of curvature of the individual elements do not fall on a straight line. The result is combined radial and tangential displacement of the image that varies with radial distance and azimuth from a point near the center of the photograph. This distortion is normally combined with radial distortions to form a combined radial, decentering distortion correction. Figure A-5 shows a combined radial, tangential distortion for a single ray. Although this correction is not often used because distortion data are not usually known, there are provisions in AMS for input of this data. Most of the current camera calibration reports now include this distortion data (see Appendix B).
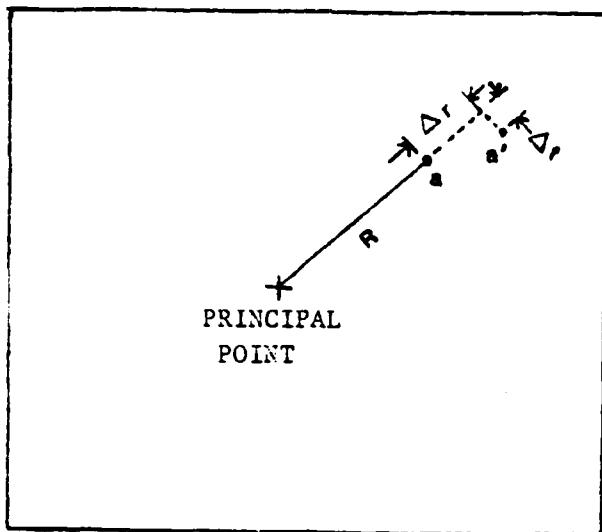
Figure A-5 - Combined Radial and Tangential Distortion
(Adapted from Wolf, 1974)

1.3   Analytical Aerotriangulation

Analytical aerotriangulation is the process through which the geometric relationship between ground space, the camera optical center, and the photographic images is mathematically modeled (Figure A-6). This concept is valid for all photogrammetric applications and sensor systems. As addressed in this section, analytical aerotriangulation will refer to aerial photography using frame and panoramic cameras. General aerotriangulation methods and principles will be explained in this section.

1.3.1   Methods

There are three primary methods of analytical aerotri-angulation: sequential, independent model, and simultaneous (bundle) adjustments. The first two are logical extensions of analog methods of triangulation as practiced for many years. They serve well to point out that analytical aerotriangulation is nothing more than a mathematical equivalent of the well known radial and mechanical triangulation methods.
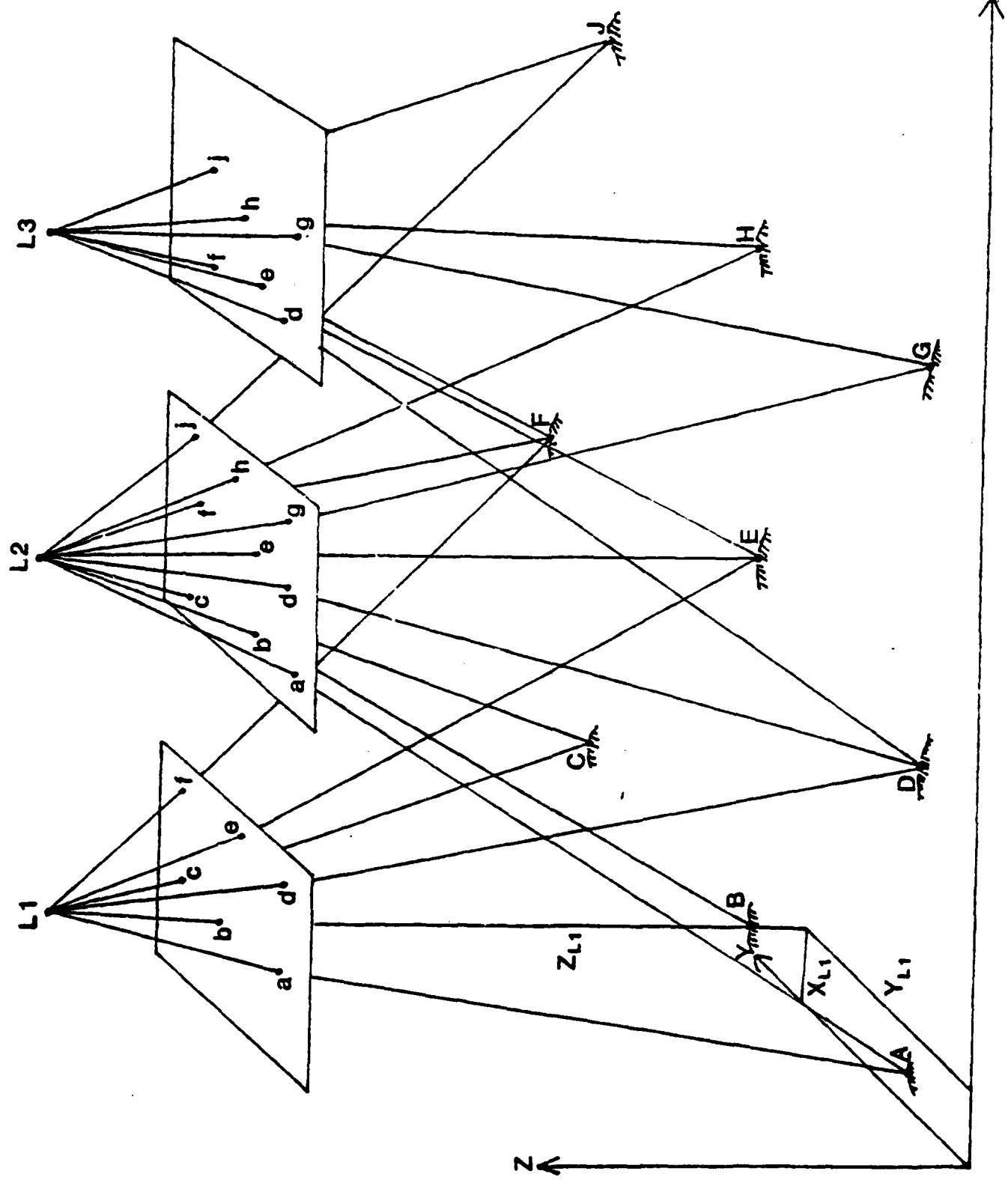
Figure A-6 - The Collinearity Condition
(Adapted from Moffitt and Mikhail, 1981)

1.3.1.1 Sequential Method

The sequential method was an early development of analytical aerotriangulation and is sometimes called the polynomial method. The procedure was developed at the National Research Council of Canada and the British Ordinance Survey. The sequence of steps in this method is:

(1) Strip aerotriangulation, with respect to an arbitrary orientation for the first photograph, and with each successive photograph oriented to the previous one.

(2) Transformation of the resulting strip coordinates to a ground control system, usually using a second or higher order polynomial to conduct a sequence of conformal two-dimensional transformations.

1.3.1.2 Independent Model Method

The Independent Model Method utilizes an arbitrary Cartesian coordinate system for each stereomodel. Each separate model is transformed to ground control in two simultaneous absolute orientations. Each model contributes seven transformation parameters to the system solution. Often, the seven parameters are separated into groups of four and three for separate but mutual solutions.

1.3.1.3 The Simultaneous or Bundle Adjustment

The Bundle Adjustment takes its name from the set of rays originating at the perspective center of a photograph and passing through all the control points, tie points, pass points, and all other points of interest on the photograph (see Figure A-6).

The bundle method is a radical departure from standard photogrammetric practice. It differs from the sequential and independent model methods in that the solution leads directly to the final coordinates in a single solution; it does not emulate an "absolute" orientation following a "relative" orientation. As a result, it is theoretically more rigorous, even if not intuitively comparable to analog methods.

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The bundle method is implemented as a part of AMS. This projective relationship between the ground space coordinates of a point (X_g, Y_g, Z_g,) and the image plane coordinates can be derived from a rearrangement of the general camera model:

$$X = f \frac{(m_{11}(X_g - X) + m_{12}(Y_g - Y) + m_{13}(Z_g - Z))}{m_{31}(X_g - X) + m_{32}(Y_g - Y) + m_{33}(Z_g - Z)}$$

$$y = f \frac{(m_{21}(X_g - X) + m_{22}(Y_g - Y) + m_{23}(Z_g - Z))}{m_{31}(X_g - X) + m_{32}(Y_g - Y) + m_{33}(Z_g - Z)}$$

For each image point measured on a photograph, one pair of equations like the above can be written. A typical bundle triangulation solution solves for the exposure parameters and unknown ground coordinates for a series of overlapping photographs.

1.3.2   Approximate Requirements for Aerotriangulation

Analytical aerotriangulation solutions employ a least squares estimation to solve for corrections to approximations of parameters. As such, they require initial estimates for the parameters.

Exposure station coordinates for each photograph can usually be scaled from an index map for the photography, and the orientation parameters initialized at w = 0, ϕ =0, and K = to the angle the flight line makes with the coordinate system east (normally 450° - Azimuth of flight). Unknown ground station coordinates can similarly be scaled from any existing maps. However the initial estimates are derived, the closer their approximations are to the final values of the adjustment, the fewer iterations and the less computer time that are required to perform the adjustment.

1.3.3   Ground Control

Ground control for aerotriangulation and mapping purposes consist of a network of image-identifiable ground points for which values referenced to a horizontal or vertical datum have been established. For aerotriangulation purposes the positions of the ground control points should be measured

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as accurately as possible.

1.3.3.1   Horizontal Control

Horizontal control points are those in which a latitude and a longitude are known (very accurately) and the vertical elevation is estimated or not as accurately known. These points should be located around the perimeter of the project area, with a minimum spacing of one point per five models. For a better solution and analysis of results, the control point density should be increased if possible.

1.3.3.2   Vertical Control Points

Vertical control points are those in which the elevation is accurately known, but latitude and longitude are estimated. These points should be located throughout the project area as well as around the perimeter, with a minimum spacing of one point every three models. Again, as with horizontal control, the greater the density the better the solution. (Note: In many cases one control point will be used for both horizontal and vertical control.)

1.3.4   Photo Control

Photo control is the network of points on the ground whose images can be seen on the photography. As misidentification can greatly affect an aerotriangulation solution these points must be precisely identified and accurately measured on the photographs. These control points must be well defined on the photograph under the magnification of the mensuration device and must also appear on a controlled map sheet. In lieu of a controlled map sheet, accurate survey data can be used if available.

Geometric requirements for ground control of mapping photography are beyond the scope of this guide, but are covered in detail in standard photogrammetric texts. An excellent reference is the Manual of Photogrammetry 1980.

1.3.5   Pass Points

Pass points are photo-identifiable points that are used to fill
in the gaps between control points. They need to be measured as accurately as
possible, but need not be identified on the ground except for a very general
latitude, longitude, and elevation estimate. Figure A-7 shows a nearly ideal
project control point distribution.

1.3.6   Optical Bar Camera Triangulation

The mathematical model presented in Section 1.1.2 of Appendix A
is well known and applies to all frame imaging situations. As described in
Section 1.1.1 of Appendix A, however, camera types exist which utilize a
dynamic imaging scheme. These cameras cannot be modeled using those
equations, and, as such, are rarely utilized in civil mapping missions.

AMS includes a single model triangulation system for panoramic
(optical bar) photography. The basic system is very similar to the frame
package, the main difference being the parameterization of the imaging
system. Panoramic cameras require a modification of the collinearity
equations:

$$x_i = f \; \frac{(R_{11}(X_i - X_{ci}) + R_{12}(Y_i - Y_{ci}) + R_{13}(Z_i - Z_{ci}))}{(R_{31}(X_i - X_{ci}) + R_{32}(Y_i - Y_{ci}) + R_{33}(Z_i - Z_{ci})}$$

$$o = f \; \frac{(R_{21}(X_i - X_{ci}) + R_{22}(Y_i - Y_{ci}) + R_{23}(Z_i - Z_{ci}))}{(R_{31}(X_i - X_{ci}) + R_{32}(Y_i - Y_{ci}) + R_{33}(Z_i - Z_{ci})}$$

where:

X_{ci}, Y_{ci}, Z_{ci}, = <u>instantaneous</u> vehicle positions

$R_{(3x3)}$ = <u>instantaneous</u> rotation matrix
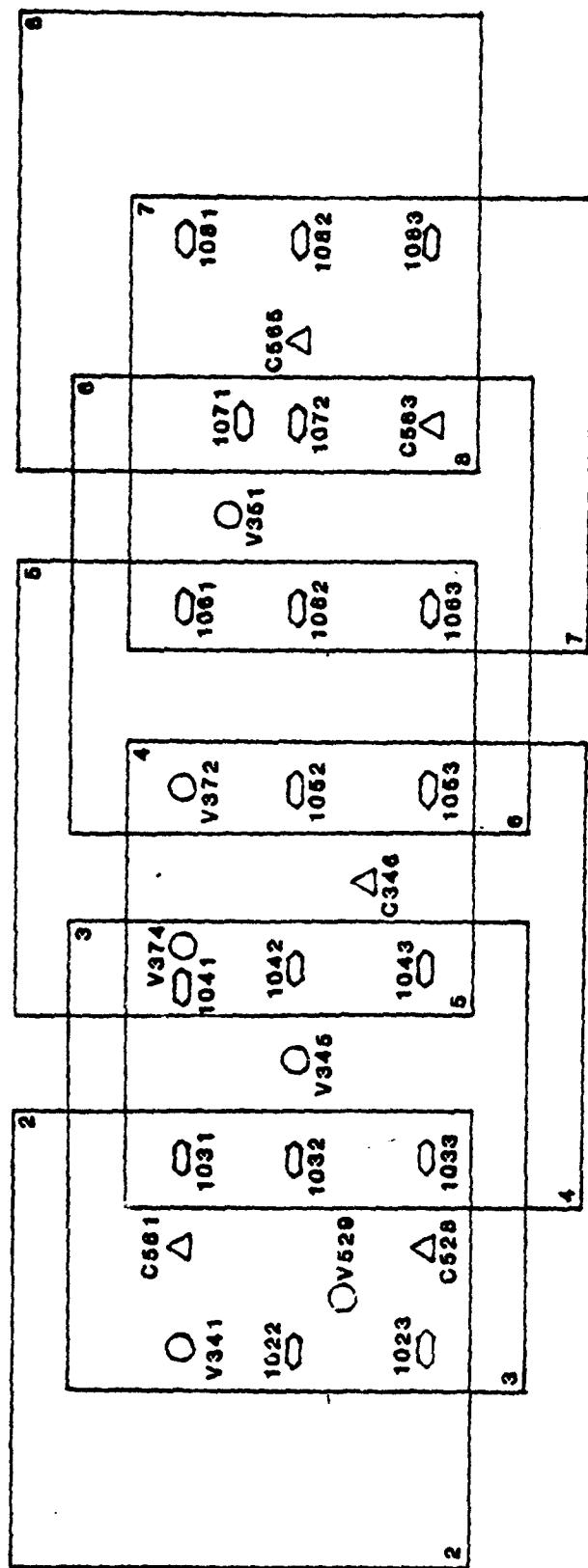
Figure A-7 - Control Distribution

△ - HORIZONTAL CONTROL POINT

○ - VERTICAL ONLY CONTROL POINT

◇ - PASS POINT

N

This collinearity can.be derived from the equation for the General Camera
Model in Section 1.1.1 of Appendix A. This aerotriagulation routine has not
yet been modified to handle multi-model applications.

1.4 <u>Interior Orientation</u>

Preceding any form of model setup on the APPS-IV (e.g.,
aerotriangulation, digitizing, etc.), the fiducial marks must be measured and
an interior orientation procedure performed. The interior orientation on the
APPS-IV is accomplished through a six-parameter transformation. The six
coefficients returned from the transformation are applied to all measured
points on the image which will transform them to machine space. Normally the
initial points used in calculating the coefficients are the measured fiducials
(usually four or eight), which have a calibrated value from the known camera
system (see Appendix B). The general form of the transformation equation is:

$$X' = a_1 + a_2 X + a_3 Y$$
$$Y' = b_1 + b_2 X + b_3 Y$$

which gives the observation equations for a least squares adjustment of n
points in the form of:

$$X'_1 = a_1 + a_2 X_1 + a_3 Y_1$$
$$Y'_1 = b_1 + b_2 X_1 + b_3 Y_1$$

where: $(X'_1 \; Y'_1)$ = "calibrated coordinates" of point i

$(X_1 \; Y_1)$ = "observed coordinates" of point i

$(a_1 \; a_2 \; a_3 \; b_1 \; b_2 \; b_3)$ = transformation coefficients

In forming the normal equations, A = observed values, B =
calibrated values, in the form:

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$$[A] = \begin{bmatrix} 1 & X_1 & Y_1 \\ 1 & X_2 & Y_2 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 1 & X_n & Y_n \end{bmatrix} \qquad [B] = \begin{bmatrix} X'_1 & Y'_1 \\ X'_2 & Y'_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ X'_n & Y'_n \end{bmatrix}$$

The normal equation is now:

$$[ATA] * [C] = [ATB]$$

where:

$$[A]^T[A] = [ATA] = \begin{bmatrix} N & \Sigma X & \Sigma Y \\ \Sigma X & \Sigma X^2 & \Sigma XY \\ \Sigma Y & \Sigma XY & \Sigma Y^2 \end{bmatrix}$$

$$[A^T][B] = [ATB] = \begin{bmatrix} \Sigma X' & \Sigma Y' \\ \Sigma XX' & \Sigma XY' \\ \Sigma X'Y & \Sigma YY' \end{bmatrix}$$

$$[C] = \begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \\ a_3 & b_3 \end{bmatrix}$$

in solving for [C] the equations become:

$$[C] = [ATA]^{-1}*[ATB]$$

The inverse of [ATA] is accomplished through a simple matrix inverse routine.

Output is now [C] which contains the six transformation coefficients, stored $(a_1\ a_2\ a_3\ b_1\ b_2\ b_3)$, and are applied to a new "observed" point to obtain new "calibrated" coordinates for that point:

$$X' = a_1 + a_2X + a_3Y$$
$$Y' = b_1 + b_2X + b_3Y$$

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APPENDIX B

CAMERA CALIBRATION REPORT

1.0   CAMERA CALIBRATION REPORT

        The following pages show (in full) an example of a camera calibration report which was used for the Seattle, Fort Lewis CAPIR Demonstration. The most important data are found on pages 1 (calibrated focal length) and 3 (calibrated principal point offsets and fiducial measurements). The aerotriangulation subsystem in AMS uses these parameters in the triangulation solution. These parameters are important in the interior orientation procedure which calibrates the photographic images to the APPS-IV stages. The subsystem also makes use of the lens distortion coefficients shown on page B-3 of this report. Many reports are not as comprehensive as this, and most older ones only give calibrated focal lengths and distances between fiducial marks. This information is entered into the camera database for use in the aerotriangulation process.
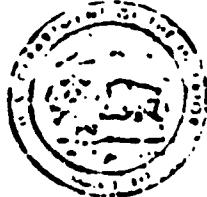
United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION   March 16, 1978

of Aerial Mapping Camera

Camera type __Zeiss RMK A 15/23__   Camera serial no. __116202__
Lens type __Zeiss Pleogon A2__   Lens serial no. __116257__
Nominal focal length __153 mm__   Maximum aperture __f/5.6__
                                           Test aperture __f/5.6__

Submitted by
Seattle District, Corps of Engineers
Seattle, Washington 98124
Reference: Seattle District Purchase Order No. DACW67-78-0222, dated February 7, 1978

These measurements were made on Kodak micro flat glass plates, 0.25 inch thick
with spectroscopic emulsion type _____V-F Panchromatic_____, developed in D-19 at
68°F for 3 minutes with continuous agitation. These photographic plates were
exposed on a multicollimator camera calibrator using a white light source rated
at approximately 3500K.

I. **Calibrated Focal Length:** 152.940 mm

This measurement is considered accurate within 0.005 mm

II. **Radial Distortion:**

Field angle (degrees)	$\overline{D}_c$	D_c for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
	µm	µm	µm	µm	µm
7.5	-4	-3	-4	-4	-3
15	-4	-5	-5	-6	-3
22.5	-4	-4	-2	-8	-2
30	1	0	1	-1	3
35	4	4	5	2	5
40	0	1	0	3	-1

The radial distortion is measured for each of 4 radii of the focal plane
separated by 90° in azimuth. To minimize plotting error due to distortion, a
full least-squares solution is used to determine the calibrated focal length.
$\overline{D}_c$ is the average distortion for a given field angle. Values of distortion
D_c based on the calibrated focal length referred to the calibrated principal
point (point of symmetry) are listed for azimuth 0°, 90°, 180°, and 270°.
The radial distortion is given in micrometres and indicates the radial displace-
ment of the image from its ideal position for the calibrated focal length. A
positive value indicates a displacement away from the center of the field.
These measurements are considered accurate within __5__ µm.

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(1 of 5)

III. Resolving power in cycles/mm   Area-weighted average resolution 91.8

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	113	113	134	113	113	80	67
Tangential lines	113	113	113	113	80	67	57

The resolving power is obtained by photographing a series of test bars and examining the resulting image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from ___5___ to ___268___ cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the B No. 116357, D No. 116404, KL 12056S and KL-F 117325 filters accompanying this camera are within ten seconds of being parallel. The B Filter was used for the calibration.

V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.3 ms = 1/230 s	81%
1/400	2.1 ms = 1/470 s	81%
1/600	1.4 ms = 1/710 s	81%
1/800	1.1 ms = 1/940 s	81%
1/1000	0.9 ms = 1/1170 s	81%

The effective shutter speeds were determined with the lens at aperture f/5.6 The method is considered accurate within 3%. The technique used is Method I described in American National Standard PH3.48-1972.

VI. Magazine Platen

The platen mounted in ___FK 24/120___ film magazine No. ___117939 and 117940___ does not depart from a true plane by more than 13 μm (0.0005 in).
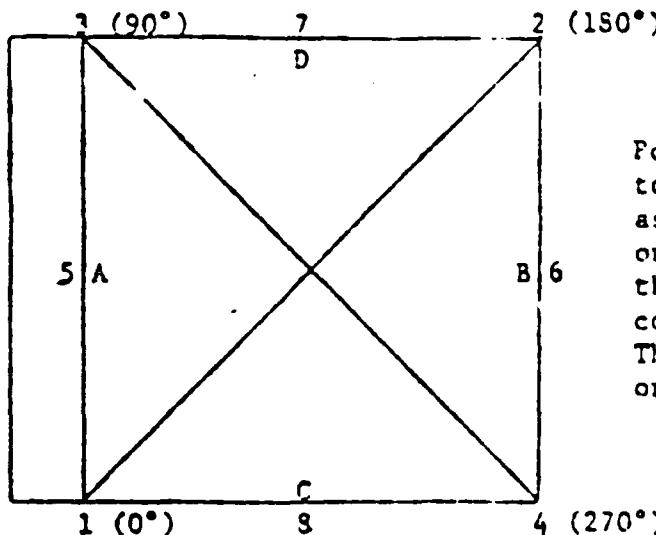
Positions of all points are referenced to the principal point of autocollimat as origin. The diagram indicates the orientation of the reference points wh the camera is viewed from the back, or contact positive with the emulsion up. The direction-of-flight fiducial mark or data strip is to the left.

	X coordinate	Y coordinate
Indicated principal point, corner fiducials		
Indicated principal point, midside fiducials	0.004 mm	0.002 mm
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	-0.007	0.001

Fiducial Marks		
1	---	---
2	---	---
3	---	---
4	---	---
5	-112.993 mm	0.002 mm
6	113.000	0.002
7	0.004	112.998
8	0.004	-112.989

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)   Not Applicable
    1-2   mm   3-4   mm
Lines joining these markers intersect at an angle of

Midside fiducials
    5-6 225.993   mm   7-8 225.986   mm
Lines joining these markers intersect at an angle of   90° 00' 01"

Corner fiducials (perimeter)   Not Applicable
    1-3   mm   2-3   mm
    1-4   mm   2-4   mm
The method of measuring these distances is considered accurate within 0.005 mm.

STEREOMODEL FLATNESS OF FIELD AND FILM RESOLUTION

Camera No. __116202__   Lens No. __116257__   Magazine No. __117939__

Focal length __152.940 mm__   Maximum angle of field tested __40°__

Base-height ratio __0.6__   Accuracy of determination __5 μm__
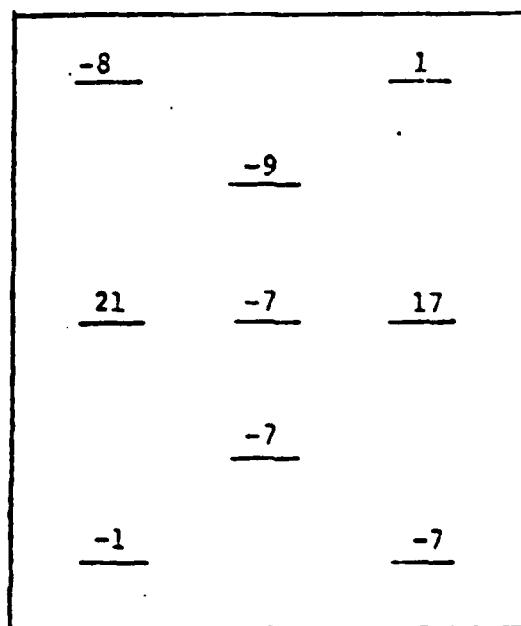

```
            -8                    1

                   -9

            21     -7      17          ⟶  Direction of
                                          flight

                   -7

            -1                    -7
```

Stereomodel
Test point array
(values in micrometres)

The values shown on the diagram are the average departures from flatness
(at negative scale) for two computer-simulated stereomodels based on
comparator measurements on contact glass (Kodak micro flat) diapositives
made from Kodak 2405 film exposures.

<u>Resolving Power, in cycles/mm</u>   Area-weighted average resolution 50.0
Film: Type 2405

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	67	67	67	67	48	40	40
Tangential lines	67	67	67	57	48	40	34

William P. Tayman
Branch of Research and Design
Topographic Division

Camera No. __116202__   Lens No. __116257__   Magazine No. __117940__

Focal length __152.940 mm__   Maximum angle of field tested __40°__

Base-height ratio __0.6__   Accuracy of determination __5 um__

<pre>
    ┌─────────────────────────────────┐
    │   -6   -4   │
    │   │   ────────────>
    │   -4   │   Direction of
    │   │   flight
    │   19   -6   14   │
    │   │
    │   │
    │   -5   │
    │   │
    │   -6   -3   │
    └─────────────────────────────────┘
</pre>

Stereomodel
Test point array
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The values shown on the diagram are the average departures from flatness
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Radial lines	67	67	67	67	48	40	40
Tangential lines	67	67	67	57	48	40	34

This report supersedes the previous calibration of this camera contained in
NBS Report of Calibration No. 208322, dated March 26, 1973.

William P. Tayman
Branch of Research and Design
Topographic Division

B-?

(5 of 5)

APPENDIX C

MOSS FUNCTIONS/COMMANDS

ACTIVE produces a table that numbers and describes the data activated by the SELECT command. Data can also be activated using the CONTIGUITY and SIZE commands.

ADD enables the database administrator to add a new map to the master map database.

AREA produces a table of area statistics (in acres), frequency and percentage of each subject associated with any polygon or raster map referenced in the active map table.

ASPECT enables the user to convert a digital terrain model to an aspect map. The aspect is either degrees from North or one of eight cardinal directions.

ASSIGN enables the user to interactively assign point and line symbologies to point and lineal features. These "font"-assigned features may be plotted with the PLOT command.

ATTRIBUTE enables a database administrator to maintain the multiple attributes data files. New attributes may be added, attributes can be updated, and reports can be generated.

AUDIT provides the user with a table containing number of points, subject, items, perimeter (in miles), area (in acres), and number of islands for each item in a vector map.

BAUD enables the user to reset the internal MOSS baud rate setting. The default baud setting of 9600 can cause considerable delays when using a 300 baud connection.

BLOWUP magnifies a portion of the display window specified by the WINDOW command. The user should display a map on the screen for orientation. The area to be magnified is indicated by pointing to two diagonal corners of a rectangle that bounds the new area of interest using the CRT crosshairs (cursor).

BSEARCH enables the user to perform complex boolean retrievals from a MOSS multiple attributes file.

BUFFER computes a user-specified zone around any vector map data referenced in the active map table. The result is a new polygon map which is stored in the polygon workfile.

CALCOMP enables the user to generate a multicolor hardcopy plot on a digital plotter. The user has total control of scale, line type (30 fonts), shade type (angle and density), and labeling. Twenty-two lettering fonts are available. The resulting cartographic product is suitable for meetings, analysis, or publication.

CBUFFER enables the user to perform raster zone generation.

CELLPLOT enables the user to generate a shaded raster map on a digital plotter. Nine shade patterns are available.

CLI enables the user to "swap in" the AOS CLI while running MOSS.

COMPOSITE ARITHMETIC enables the user to algebraically manipulate raster data. Maps can be weighted and added, subtracted, multiplied, or divided. The new map is stored in the database.

COMPOSITE LOGICAL enables the user to perform boolean manipulations of raster data using one or more maps. The result of combining data with the COMPOSITE LOGICAL command is a new cell map.

CONTIGUITY helps the user determine "what is next to what?" For example, the user may have a vegetation map and wants to determine how many polygons of ponderosa pine are adjacent or contiguous to polygons of Douglas fir. The result of using CONTIGUITY would be a new map of all Douglas fir polygons that are contiguous to ponderosa pine.

CONTOUR generates a contour map from a digital terrain model.

COST enables the user to find out how much CPU time and how many disk accesses have been made during a MOSS run. If a costing function is available, it will also print out the cost of the current MOSS run.

DEBUG enables the system manager to "turn on" and "turn off" debug messages. These messages are useful for tracking down software/data problems.

DELETE enables the user to delete a map from the MOSS database.

DISTANCE measures the distance in miles and kilometers between two points on the CRT either along a straight line or along a path. The beginning and end points of the DISTANCE measurement are identified by using the CRT crosshairs (cursor).

DUMP is a system manager function that prints the contents of a MOSS vector map to the screen. These dumps are useful for tracking data problems.

EDGE activates edges or common boundaries shared by subjects associated with two or more maps referenced in the active map table. The result of the EDGE command is a line map of the common boundaries shared by the input maps.

EDITATT enables the user to interactively edit individual files for a feature in a MOSS multiple attributes file.

ERASE clears the CRT display screen and resets the crosshairs (cursor) to the upper left-hand corner of the screen.

EXPORT enables the user to generate an ASCII text file from a vector map. This text file is in a suitable format for export to other installations or geoprocessing systems.

FINISH enables the user to terminate the MOSS program. After this command is initiated, the user is returned to the computer operating system. The user can then initiate other programs or type the word BYE and log off the computer operating system.

FREE is used to 'deactivate' any map referenced by the ACTIVE command.

FREQUENCY produces a table showing the frequency and percentage of each subject associated with any polygon map referenced in the active map table. Frequency is defined as the number of polygons.

GENERATE enables the user to interactively create a new MOSS map. Interaction is via the terminal cursor. Points, lines, polygons, circles, and rectangles may be created.

GRID performs point to grid interpolation. This command converts three-dimensional point samples to a digital elevation model.

HELP provides either a listing of the MOSS commands or a general description of the capabilities of a specific command.

LEGEND enables the user to label points, lines, and polygons displayed on a CRT.

LENGTH produces a table showing the length (in miles), frequency, and percent of each subject associated with any line map referenced in the active map table.

LINE plots line data in any one of 18 symbologies.

LIST browses the contents of MOSS map files. The LIST command performs four basic tasks:

      (1) Lists the names of the maps stored in the master map file and the user's cell or polygon workfile.

      (2) Lists the subjects for a particular map.

      (3) Lists the header information for a particular map.

      (4) Browses through the multiple attributes database for a map.

LOCATE determines the Universal Transverse Mercator (UTM) coordinates of any point on the map being displayed on the graphics display terminal.

LPOVER enables the user to perform an intersection between a polygon data set and a point or line data set. The result, another point or line data set, is stored in the user's polygon workfile.

MERGE combines two or more active maps and creates a new map in the polygon workfile.

MODELG enables the user to perform complex boolean modeling functions against a MOSS multivariable grid file.

MULTIVAL converts a MOSS single variable file to a MOSS multivariable file.

NEWS enables the user to type out the contents of the current MOSS news file. This file contains information on the latest changes to MOSS.

NUMBER enables the user to either print the item number of each feature in a displayed map or to assign code numbers to groups of features on a displayed map.

OPEN enables the user to access an alternative master map database.

OVERLAY synthesizes a new map by determining the polygon intersection between two polygon maps referenced in the active map table. OVERLAY uses two active maps as input and creates a new active map as output.

PERIMETER gives the user the length of perimeters (in miles) for each subject of a given polygon map.

PLOT displays data that have been activated by the SELECT command. Each map set to be plotted is specified by using its unique integer code identifier, which may be found by using the ACTIVE command.

POINTOVER performs a polygon on point overlay (Point in Polygon). Typical uses might be to produce a count of water wells by coal lease area or a count of oil wells by section.

POLYCELL converts point, line, or polygon data to raster format.

PROFILE enables the user to point with the CRT crosshairs (cursor) to two locations on a raster map or a digital terrain model and have the surface profile between the two points computed and displayed.

PROJECTION enables the user to convert coordinate data from one projection or coordinate system to any one of 20 other coordinate or projection systems.

PROXIMITY activates data from a map(s) based on its proximity to some point or other map feature. A typical query for PROXIMITY might be "give me all the ponds within 0.5 miles of a paved road."

QUERY identifies the map name, subject, and item of any point, line, or polygon being displayed on the screen. The user uses the CRT crosshairs (cursor) to point to the item of interest.

RASTER is a database utility function that allows the user to:
    (1) window raster maps
    (2) apply scalers to cell values
    (3) change individual cell values
    (4) recode entire raster maps

REPORT enables the user to generate tables (up to seven columns wide) from data stored in a map's multiple attribute file. There may be up to 200 attributes per map item (point, line, or polygon).

RESET returns the data display window from the BLOWUP window to the window specified by the WINDOW command.

SAMPLE enables the user to select a random sample of features from any MOSS vector map.

SAVE saves a map referenced in the active map table as part of the user's workfile.

SELECT activates all or a specific portion of a map that is stored in a MOSS map file. The SELECT command may be used to activate an entire map based on primary subject, sub-attributes, or individual map items.

SHADE plots activated polygon map data on the screen and shades the polygons with differential cross-hatching. If more than one active map ID number is entered following the SHADE command, each map will be plotted with different degrees of cross-hatching.

SIZE activates polygons or lines on an active map based on the size or length of these polygons or lines.

SLOPE enables the user to convert a digital terrain model to a slope map.

SNGVAL converts a single field in a MOSS multivariable file into a MOSS single variable file.

SPSS enables the user to generate a data matrix from a set of raster maps. This data matrix is suitable for input into such statistical packages as SAS, SPSS, and BMD. There is also an option to build a multivariable grid cell file for input into other geoprocessing systems.

STATISTICS CROSS-TABS produces a two-way frequency table of the contents of two cell maps referenced in the active map tble.

STATISTICS DESCRIBE computes the following parameters for each subject asociated with an active map:

      (1) the minimum area or length

      (2) the maximum area or length

      (3) the total area or length

      (4) the range, mean, variance, and standard deviation

STATISTICS HISTOGRAM produces a bar graph or histogram of the frequency distribution of the subjects in any active map (vector or raster).

STATUS prints out the number of items and coordinate pairs for:

        (1)   all the maps in the master file

        (2)   a particular map in the master file or

        (3)   any map referenced in the active map table.

STUDYAREA constructs a new boundary around any map or series of maps referenced in the active map table.

SYMBOL enables the user to select any one of 20 symbols and have that symbol plotted for point or polygon data. There are several options to the SYMBOL command.

TESTGRID superimposes a grid over any map displayed on the screen. The cell size is user-specified in acres. TESTGRID is useful for helping the user determine the appropriate cell size when converting a polygon map to a cell map.

TEXT enables the user to create, edit, and display layers of textual information. The text is tied to the ground and is treated as a special type of MOSS Map. Twenty text fonts are available.

THREED enables the user to display any raster map or digital terrain model in a three-dimensional format.

TRANSLATE enables the user to "move" a map from one location on the surface of the earth to another. This command is useful for registering data sets.

WEED culls all unnecessary or undesired data points.

WINDOW enables the user to set a virtual display window for one or more vector or raster maps.

WRITE enables the user to generate a line printer map from a discrete raster map.

END

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